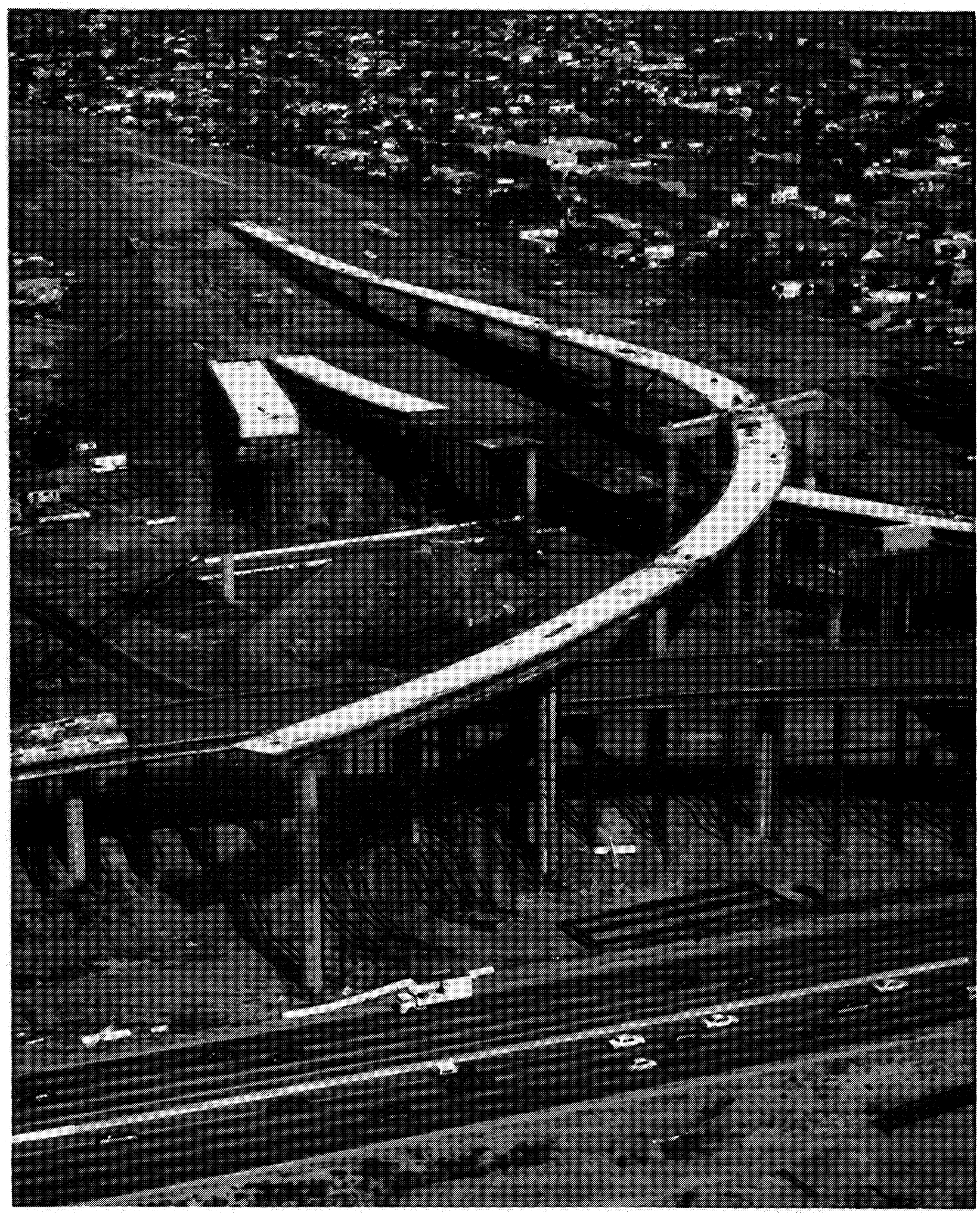
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES

PRESTRESS MANUAL

(A GUIDE FOR FIELD INSPECTION OF CAST-IN-PLACE POST TENSIONED STRUCTURES)



MAY 1992

CALIFORNIA PRESTRESS MANUAL

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INTRODUCTION

A major portion of the bridges built in California are prestressed, post-tensioned type structures. As a Bridge Engineer working in construction, you will be involved with and should understand the construction principles relating to prestressed, post-tensioned bridge construction.

This prestress manual has been compiled to provide the Engineer with the necessary information and background to perform three basic duties:

1. Check the Contractor's working drawings.
2. Provide thorough and complete inspection during the construction of the bridge with respect to stressing.
3. Understand and enforce Section 50 'Prestress Concrete' of the Standard Specifications and any pertinent references.

The information included herein is to be considered as a reference and guideline. It should be reviewed prior to working drawing review and during the prestressing. This manual should be available to the field engineer during the prestressing operation.

This manual along with good communication between the Structure Representative, Design, Translab, and the Contractor will provide a product of sound structural integrity with a minimal amount of construction related problems.

SAFETY

The prestressing operation can be a potentially dangerous one. Due to the tremendous forces involved, if a failure occurs there is a good possibility that high velocity projectiles will be produced. The field engineer should always stay alert and be aware of the Contractor's movements.

General common sense rules to be practiced around and during the prestressing operation are as follows:

1. Stay clear of the area when the Contractor is unpacking the strands. Securing bands may spring in any direction when released.
2. Before the contractor begins the stressing operation, check all of the high pressure hoses for leaks and/or poor condition. Worn or damaged hoses are to be replaced only with hoses that can withstand the pressures involved.
3. Never stand behind the prestressing jack during the stressing operation. Use caution around the tendons until after they are grouted.
4. Always be aware of the Contractor's operation and equipment during the stressing.
5. The Load Cell Indicator Box is very expensive. Do not leave it unattended and make sure the contractor does not damage it with his equipment. After verifying the gage pressures, the pressure cell and readout box

should be relocated to a safe location away from the immediate area.

6. If the contractor uses a corrosion inhibitor, avoid contact with the eyes or skin. Goggles, coveralls, boots, and impervious gloves should be worn for protection.

PRESTRESS WORKING DRAWINGS

Section 50-1.02 of the Standard Specifications requires that the contractor submit working drawings of the prestressing system that will be used. It is the Contractor's responsibility to use a system approved by Caltrans or obtain approval from the Translab for the system which is proposed for use.

The working drawings are to be submitted by the Contractor to the Documents Unit in Sacramento (STD. SPEC. 50-l). They will distribute the various sets of drawings for review and approval. The distribution is outlined in Bridge Construction Memo 160-6.0.

The responsibility for checking the working drawings is shared by the designer and the Structure Representative. Working drawings shall not be returned to the Contractor until the designer has discussed and resolved the details with the Structure Representative. The comments returned to the Contractor must be acceptable to both the designer and the Structure Representative.

The normal time allowed for working drawing review by Caltrans is 6 weeks for structures not involving railroads and 8 weeks for structures which do involve railroads.

The Standard Specifications, Special Provisions, Contract Plans, Standard Plans, Bridge Construction Records and Procedure Manual, and RE pending file should be carefully reviewed before and during the working drawing review. All dimensions, layouts, and calculations shall be checked Items of specific concern are as follows:

1. Prestressing force and theoretical elongations.
2. The force variation between girders.
3. Bearing plate stresses and concrete stresses behind the bearing plates.
4. Whether one or two end stressing.
5. Duct layout and reinforcement conflicts.
6. Blockout sizes and possible utility conflicts.

For a checklist on reviewing working drawings see Appendix C-Inspection Checklist.

It is important that all parties involved (Designer, Structure Representative, Inspecting Engineer, Contractor, and Subcontractor) are working from an <u>Approved</u> set of Working Drawings.

It may occur that the Contractor will begin construction from an unapproved set of working drawings. The Contractor should be reminded (and noted in the diary) that all work will be checked with a approved set of working drawings and any deficiencies will require correction and that no concrete will be placed until the corrections have been made.

At the completion of all the structures on the Contract, the contractor shall submit one set of 35 mm microfilms of the approved working drawings for each structure (Std. Spec. 50-1.02). If the Structure Representative receives these items, they should immediately be forwarded to the Office of Structures Design, Documents Unit, P.O. BOX 942874, Sacramento 94274-0001 as outlined in Memo 160-6.0 of the Bridge Construction Records and Procedures Manual.

RIGID DUCT

Section 50-1.07 of the Standard Specifications requires that the duct enclosures for prestressing steel be RIGID ferrous metal, galvanized, mortar tight, and accurately placed as shown on the Contract Plans or as approved by the Engineer.

Rigid duct is used to take advantage of the low tendon-to-duct friction inherent with rigid duct. The rigid type duct is stiff enough to eliminate horizontal wobble but limber enough to bend and meet the required tendon profiles. The reduced friction coefficients associated with rigid duct as compared to that of flexible duct can result in 10% to 50% reduction of prestressing steel required, depending on the length of structure.

Rigid duct is available in various types and diameters. One type of duct is the smooth wall type, made from strip steel held together longitudinally with a continuous resistance weld or a continuous interlocking seam, The duct is normally furnished in 20-foot lengths with one end of each length enlarged to form a slip type Connection. Another type of rigid duct is made from ribbed sheet steel with helically wound interlocking seams. This duct is generally furnished in 40-foot lengths and is connected by larger rigid duct couplers. A third type of rigid duct which is approved for State use is the VSL shallow elliptical or rectangular type, This type is used occasionally for transverse deck stressing.

The rigid ducts are to be field released by the Engineer. The ducts will not have release tags attached when they arrive on the jobsite. The ducts are to be checked for specification compliance and any damage that may have occurred during shipping. Damaged duct can be repaired if the damage is minor but shall be rejected if the damage is extensive. The placement of the ducts can be checked using the duct checker, (Photo 5) (Bridge Construction Records and Procedures Memo 145-7.0) or with an engineer% rule and a level. Most tendon paths are parabolic and the distance from the soffit forms to the CG of the path can be calculated as shown below:

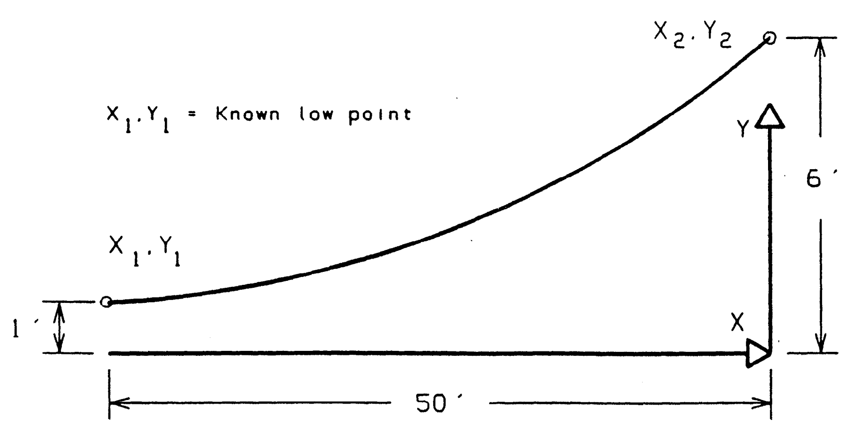
Calculation of points on a parabolic curve

$$y = ax^2 + c$$

EXAMPLE X, = 0, Y, = l and $X_2 = 50$, $Y_2 = 6$

$6 = a(50)^2 + 1 \quad a = l/500$

$Y = (1/500)X^2 + 1$



The final check for the duct alignment should be verified by eyeballing for a smooth tendon path. It is recommended that the taped duct joints (Photo 3) be staggered for multiple tendon girders so that a misalignment of the ducts does not occur. Section 5O-l.07 of the Standard Specifications requires that waterproof tape be used at all duct connections.

Duct vents are required on ducts with a total length of 400 feet or more and shall be located within 6 feet of a high point in the duct profile. Locating these vents on either side of the bent cap centerline may avoid possible conflicts with the top cap Steel.

The Contractor is required to protect the ducts from any water or debris from entering them prior to the placement of the stressing Steel. Section 50-1.07 of the Standard Specifications states that the ducts shall be covered at all times after installation into the forms. The Contractor is required to prove that the ducts are free and unobstructed twice as follows:

1. Prior to placing forms for closing slabs of box girder cells, Std. Spec. 50-1.08.
2. Immediately prior to installation of prestress steel, Std. Spec. 5O-l.O7

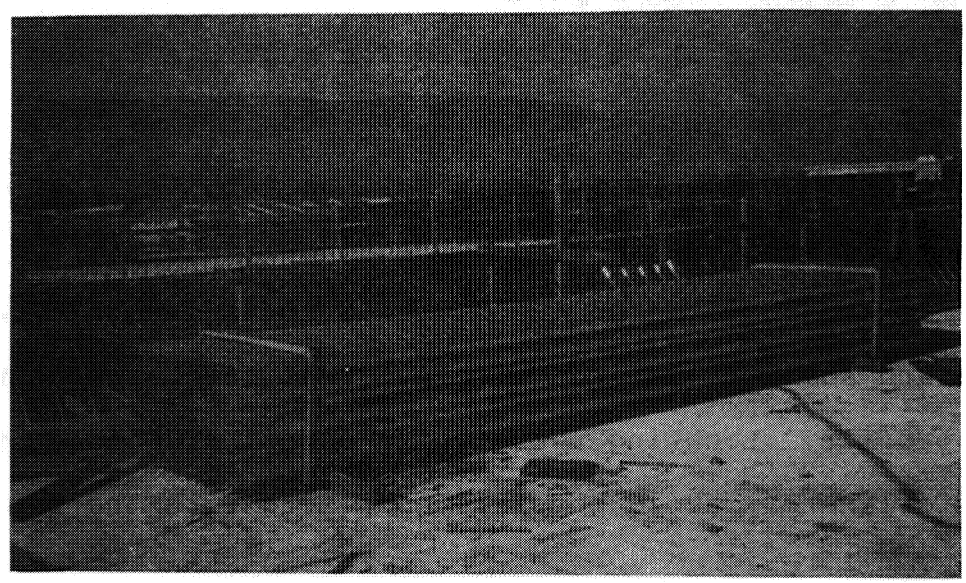


PHOTO 1

Ducts Arriving on the jobsite

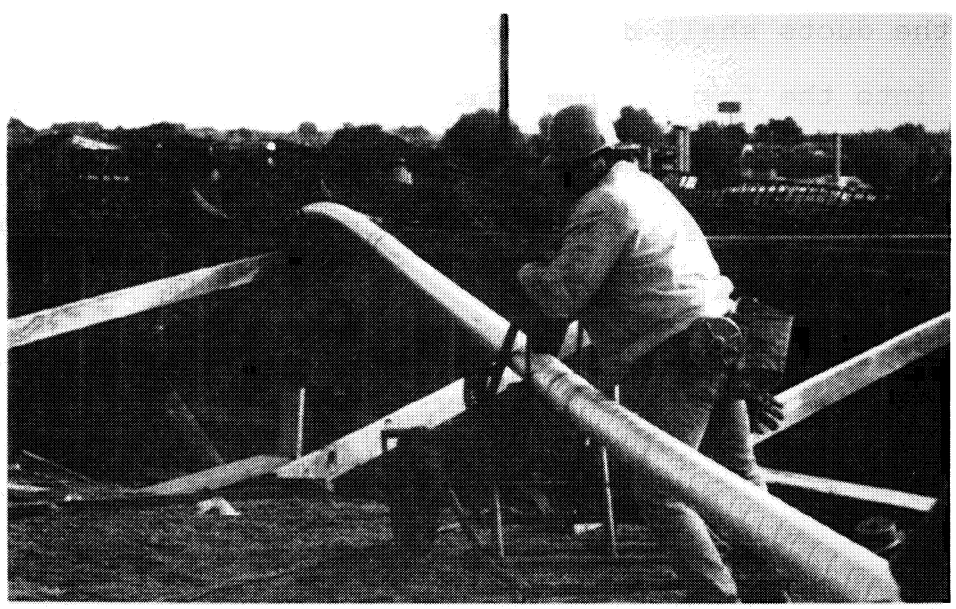


PHOTO 2

Placing Ducts into the bridge with a Duct Pusher

PHOTO 3

Splicing Ducts with waterproof tape.

PHOTO 4

Checking Duct Profile

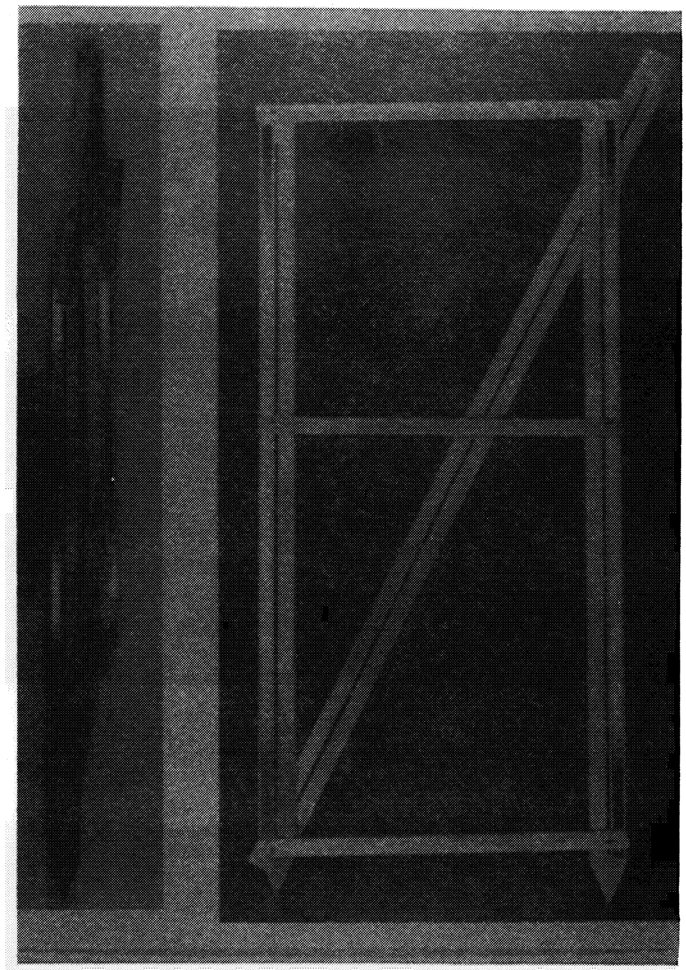


PHOTO 5

Duct Checker
Ref: Bridge Construction Record and Procedures Memo 145-7.0

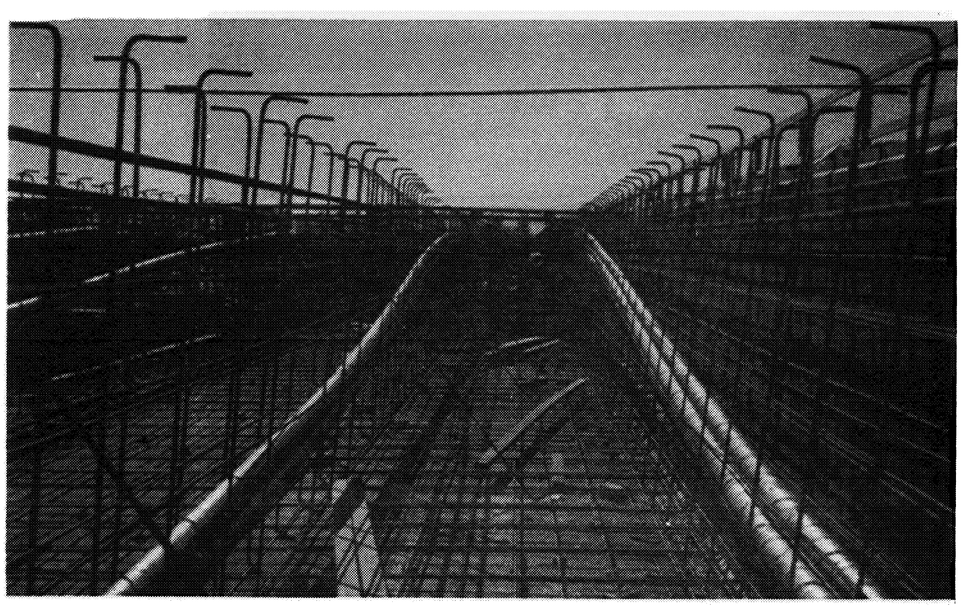


PHOTO 6

Parabolic Duct Profile over Bent cap.

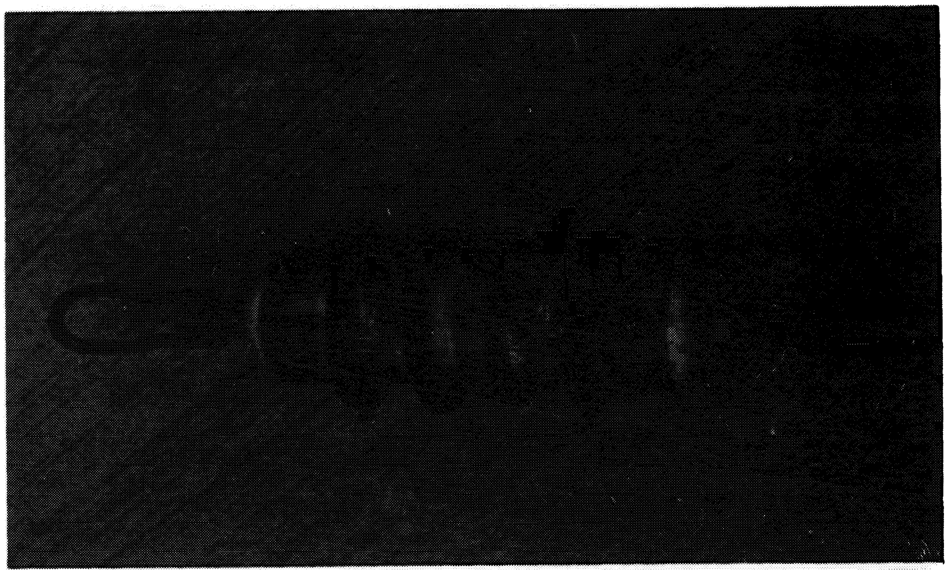


PHOTO 7

The Bullet-used for checking for water and debris in the duct.

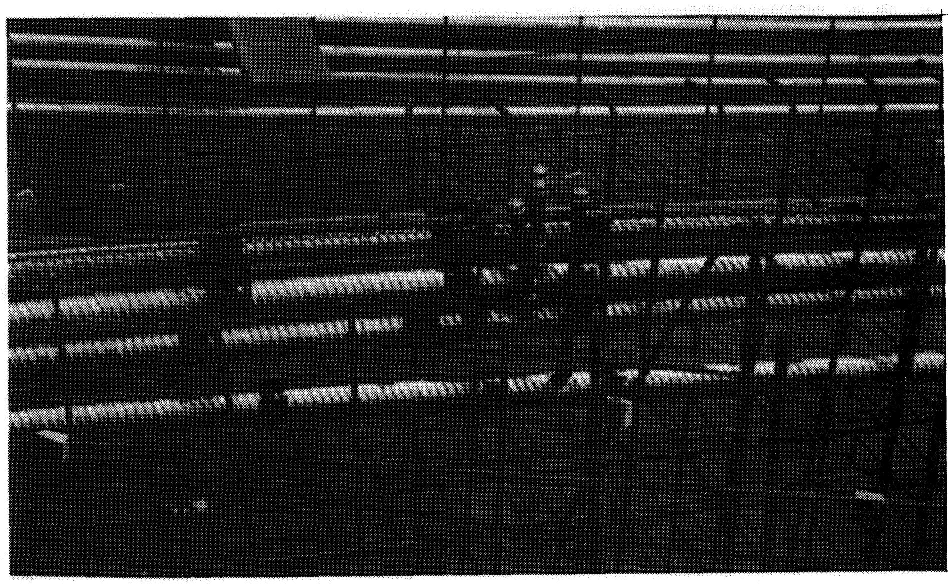


PHOTO 8

Duct Vents

STRANDS/RODS

Steel used for prestressing must conform to the requirements of ASTM designations A416, A421, or A722, as well as Section 50-1.05 of the Standard Specifications. The A416 designation covers the requirements for both 0.5" and 0.6" strand. The A421 designation gives requirements for prestressing wire. The A722 designation gives requirements for high-strength steel bars. Figures 1, 2, and 3 show typical stress strain curves and physical properties for l/2", 0.6" strand, and grade 150 bars.

All strand is the seven wire type with a center wire enclosed by six helically placed outer wires. The center wire is slightly larger then the outer six. Strand is stress relieved by continuous heat treatment, a process which produces a slight bluish tint to the strands. The ASTM specifications allow one butt welded wire per 150 foot of strand, but only during the fabrication process. Under no circumstances should welding of joints in strands or wires be allowed in the field.

The Standard Specifications allow the use of couplers for extending plain or deformed bars. The locations of couplers are subject to approval of the Engineer and shall be shown on the Contractor's working drawings.

Effective packaging of prestressing steel is necessary to protect the material from physical damage and corrosion.

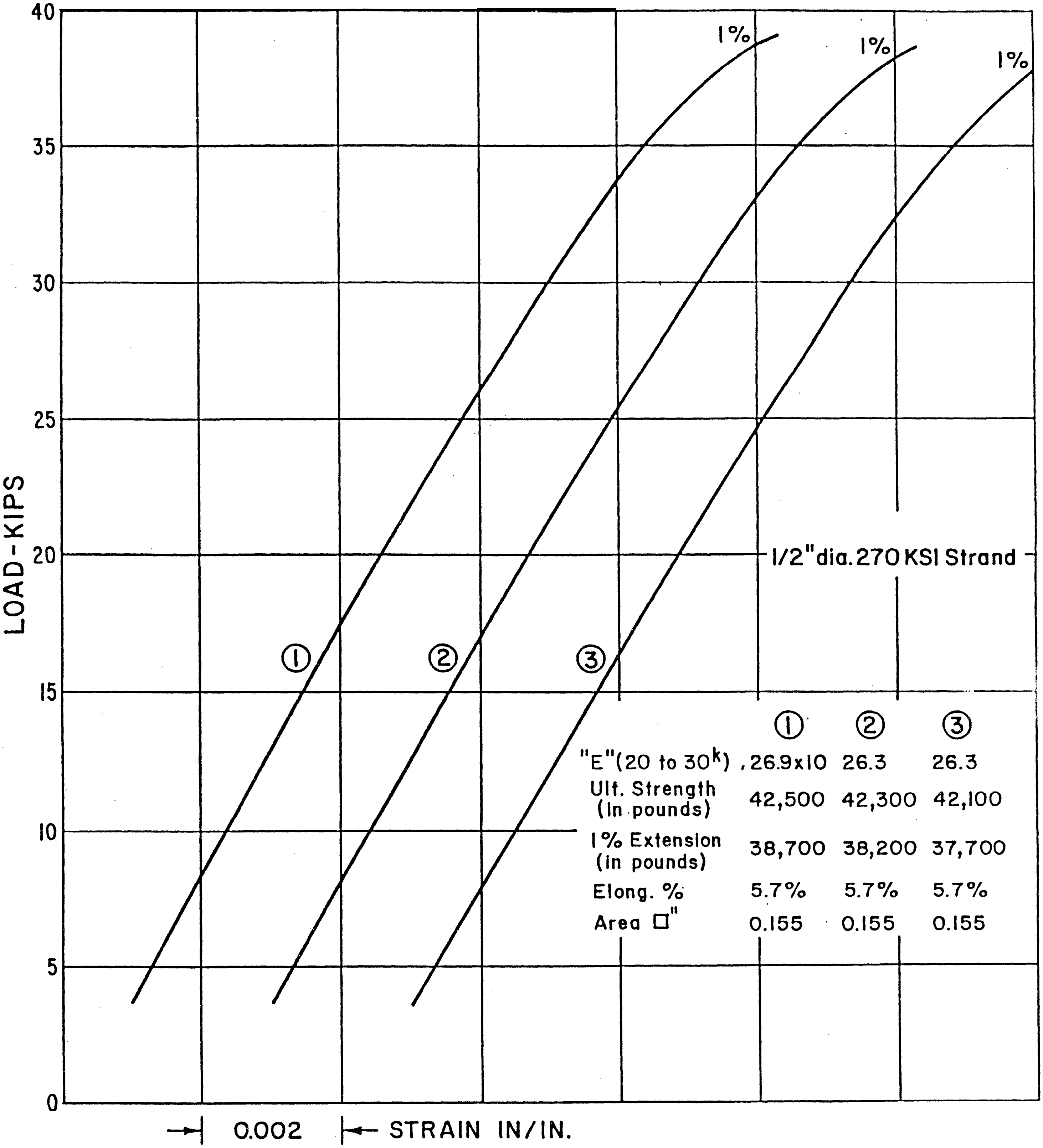


FIGURE 1 TYPICAL STRESS - STRAIN CURVE

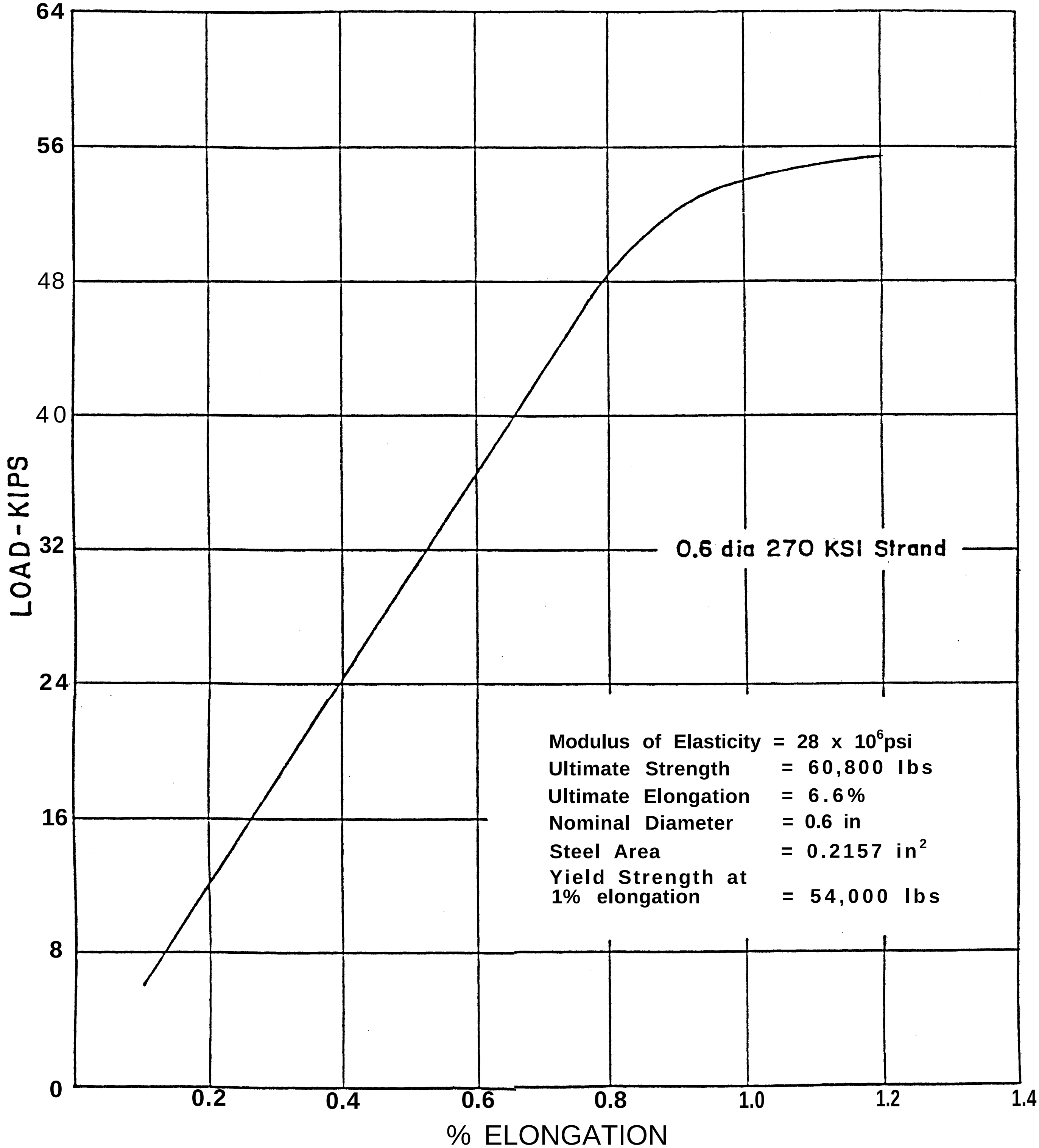


FIGURE 2 TYPICAL STRESS - STRAIN CURVE

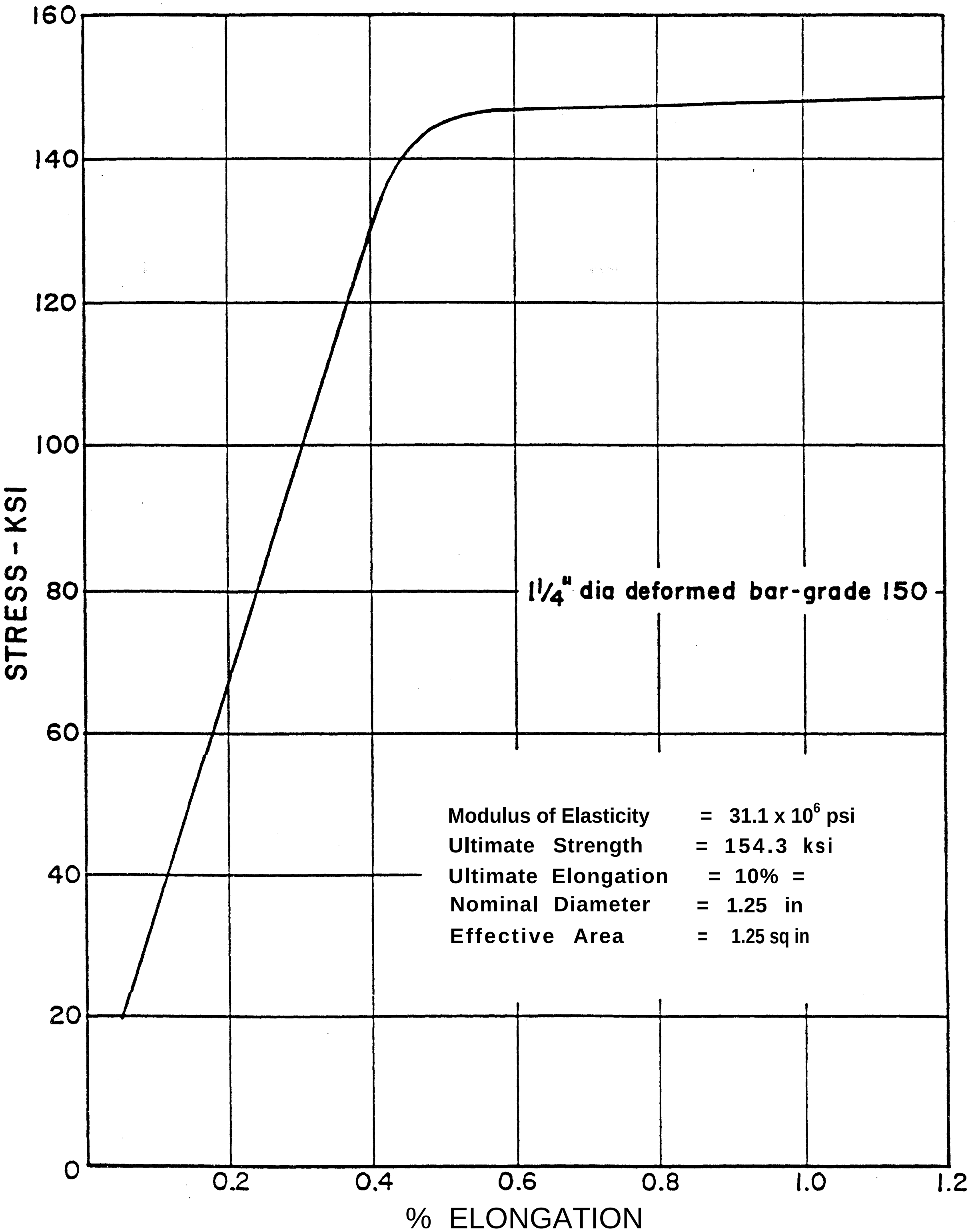


FIGURE 3 TYPICAL STRESS - STRAIN CURVE

The packs should be inspected for physical damage immediately upon arriving at the jobsite. Any damaged pack must be replaced or restored to its original condition. The shipping package or form shall be clearly marked with a statement that the package contains high-strength prestressing steel, and the type of corrosion inhibitor used, including the date packaged. A release tag will be delivered with the strand. The release tags, which will have the area, (A) and the modulus of elasticity, (E) of the strand will be attached to the individual packs. Collect one of the tags and initial the remaining tags. On the collected tag, record the (A's and E's), and attach to a TL-29 for the job records.

Prior to placement, it is important that prestressing steel be checked for corrosion or damage. A very small pit or crack in high-strength wire or rod will allow a stress concentration at that point and could cause an abrupt failure of an individual rod or wire. Tests performed by the Transportation Laboratory on rods with l/32" deep pits resulted in reductions of strength varying up to 50 percent.

Section 50-1.05 of the Standard Specifications states that all prestressing steel shall be protected at all times against physical damage and rust or other results of corrosion from manufacture to grouting or encasing in concrete. Prestressing steel that has sustained physical damage at any time shall be rejected.

The following is presented as a guide for inspection of prestress steel for rust before installation in ducts:

1. Upon opening, if there is an even coating of rust over the strands in the entire pack, the pack should be rejected. This situation indicates improper handling or storage.

2. If there are one or more wires in a strand which shows extensive rust throughout its length, the entire pack should be rejected. The wire was probably rusty when the strand was wound.

3. When there are spots of rust on a portion of strands in the pack, especially on the inside of the coil, this is the likely effect of condensation, usually caused by temperature changes during shipment or storage. If these spots can be removed by rubbing or scraping with the fingernail, the steel is acceptable. If light streaks of rust remain, the steel is still acceptable if pitting is not present.

4. Short sections of strand which contain clinging rust, pits, or other flaws should be rejected without rejecting the entire pack.

The above criteria can generally be applied to rods as well as strand. In addition, any loose mill scale on rods should be removed in a manner which will not damage the material. Prior to rejecting prestress steel, contact the Structure Representative or Construction Engineer.

It is required that the prestressing steel be checked for rust and other flaws, as described above, while the tendons are being made up and before placing in the ducts. During the placement operation, inspection should also be provided for proper make-up of tendons, and for care in keeping the steel and ducts clean and free from any foreign material or damage from handling. Prestress steel should preferably be cut with a carborundum blade. Flame cutting may be used provided proper care can be exercised near anchorages. Cold-chiseling should be avoided near anchorages. Exposure to electrical current (i.e, arc welding) should not be allowed, unless approved by the Engineer.

A corrosion inhibitor must be applied, if prestressing steel is placed in ducts prior to placing and curing of concrete. If the steel is placed after placement of the concrete, a corrosion inhibitor shall be required if the stressing and grouting are not completed within 10 days. The contractor shall provide an approved corrosion inhibitor which prevents rust or corrosion.

V.P.I. Powder, which stands for Vapor Phase Inhibitor Powder, is a common method used by the contractor to protect the prestressing strand. When properly applied, the powder is absorbed onto the metal surfaces to form an invisible film. This film passivates the metal and inhibits corrosion.

The manufacturers recommendations should be used when applying the powder. The ducts shall be reasonably dry. The powder is applied into the ducts by use of a floc gun. The application concentration is typically one gram (0.035 ounces) per cubic foot of enclosed space or one gram per square foot of metal surface whichever is greater.

V.P.I. Powder contains dicyclohexylamine nitrite and is moderately toxic. Repeated exposure may cause damage to the kidneys, liver, central nervous system and blood. Avoid contact with eyes or skin. Goggles, coveralls, impervious gloves and boots should be worn when handling the powder.

The Contractor shall include provisions for placing V.P.I. powder on the working drawings. The provisions shall include the manufacturer's technical data, application rate and a Material Safety Data Sheet.

BEARING PLATES

Approved permanent type anchorage devices shall be shown on the working drawings, Section 50-1.06 of the Standard Specifications requires that the final unit compressive strength stress on the concrete behind the bearing plate shall not exceed 3000 psi. The bending stresses in the plates shall not exceed the yield point of the material when 95% of the specified ultimate tensile strength is applied.

The bearing plates shall be tested and released by the Translab. A TL-29 release form and a release tag are required prior to incorporating the bearing plates into the work.

The bearing plates are to be placed perpendicular to the slope of the prestress duct. The batter of the bearing plate should be checked during the working drawing review and confirmed while the prestress blockouts are being formed,

WEDGES

The specifications require all permanent anchorage devices for post-tensioning to develop at least 95% of the guaranteed ultimate tensile strength of the prestressing steel. The anchorage systems develop the required strength through the interplay between wedges and prestress steel, and between the wedges and anchorage plate. Characteristics which affect this interplay are wedge angle, wedge teeth, type of steel, type of heat treatment, and general strand configuration in the anchor plate.

The care, cleanliness, lubrication, surface condition and finish also affect the efficiency of wedge systems. All manufacturers have quality control procedures which should eliminate obvious manufacturing defects. On-the-job care is left to the discretion of the individual field crews. The Contractor must use wedges that have been approved by the Translab. Pulling wedges may not be used as permanent wedges.

The wedge holes of the anchor block should be clean prior to placing the permanent wedges. Sand or foreign particles located in the wedge area of the anchor block can cause the wedges to fail.

JACKS

Jacks used in typical post tensioning systems are generally the center hole variety. (See Figures 4 and 5 for an example).

Prestress jacks have more wearing surface, longer jack stroke, and packing than conventional jacks of the same capacity. This increases the potential of variations in the accuracy of the applied force. Other conditions which may affect accuracy and efficiency of hydraulic units are: Use of unfiltered oil, exposure of the system to dust or grit, eccentric loading, type of packing, ram position, oil temperature, hydraulic valves, ram and packing maintenance, and readout equipment. Care and effort must be exercised to attain accuracy from the jacking equipment.

A condition which must be considered when using hydraulic jacks is hysteresis. Hysteresis is an energy loss due to a hydraulic pressure change inside the jack, causing inaccurate load values when the ram pressure is static or decreasing. An increase of hydraulic pressure also causes an energy loss, but this loss is taken care of by calibrating the jack and pressure gage with a load cell during this increase of pressure.

Improper gage readings occur when the ram is fully extended and the hydraulic pressure is dissipated against the jack case. This condition can cause harm only if it damages the jack or gage and if the gage reading is mistaken for actual tendon stress,

The stroke should be monitored by the contractor, Typically jacks have a 12 inch stroke and if the ram is extended beyond this limit the jack will be damaged.

Fittings and valves are a common source of problems. The fittings are equipped with spring-loaded, self-closing ball valves, which occasionally will not open when joined together. If this occurs anywhere except in the gage line, the system will not work and a high gage reading will show immediately. If the stuck valve is in the gage line, everything will work except the gage. Valves and fittings that leak or will not hold the load should be replaced. When fittings are replaced it is imperative that high pressure type fittings are used. (e.g. Schedule 80) If you have any questions concerning high pressure fittings contact the Trans Lab.

In general, jacks are about ninety-five percent efficient, but actual efficiency will vary depending on the age and condition of the jack. Suspect any calibration chart which shows jacking forces much greater than ninety-five percent of pressure times piston area. Load cells and pressure gages are available to check any questionable equipment.

Department policy recommends that the jacks should be calibrated yearly. If it has been more than one year since the last calibration, contact the Transportation Laboratory in Sacramento or Office of Structures Construction. The Structure Construction Computer Bulletin Board has current information for jacks used in all State approved stressing systems.

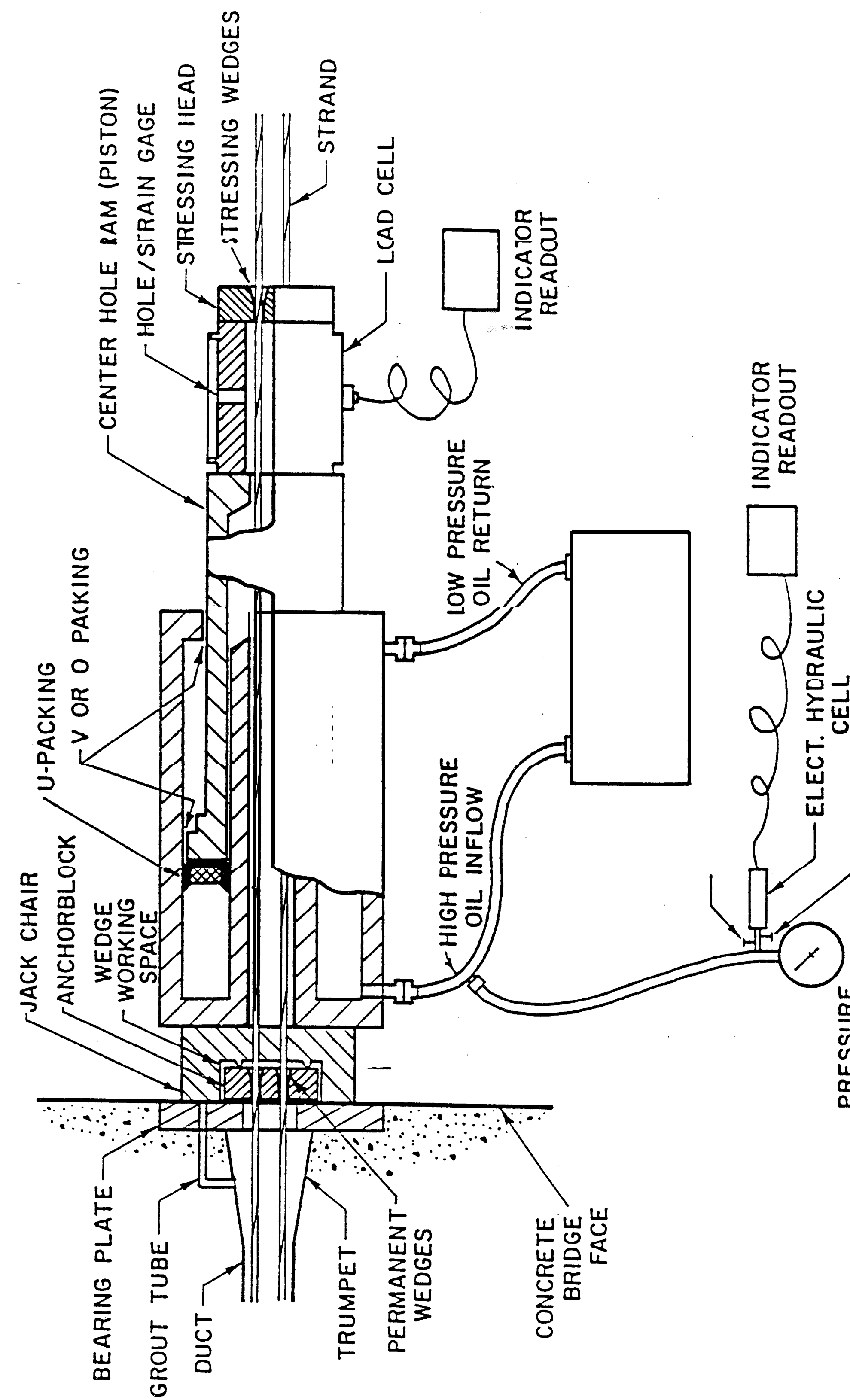


FIGURE 4 TYPICAL POST TENSIONING SYSTEM

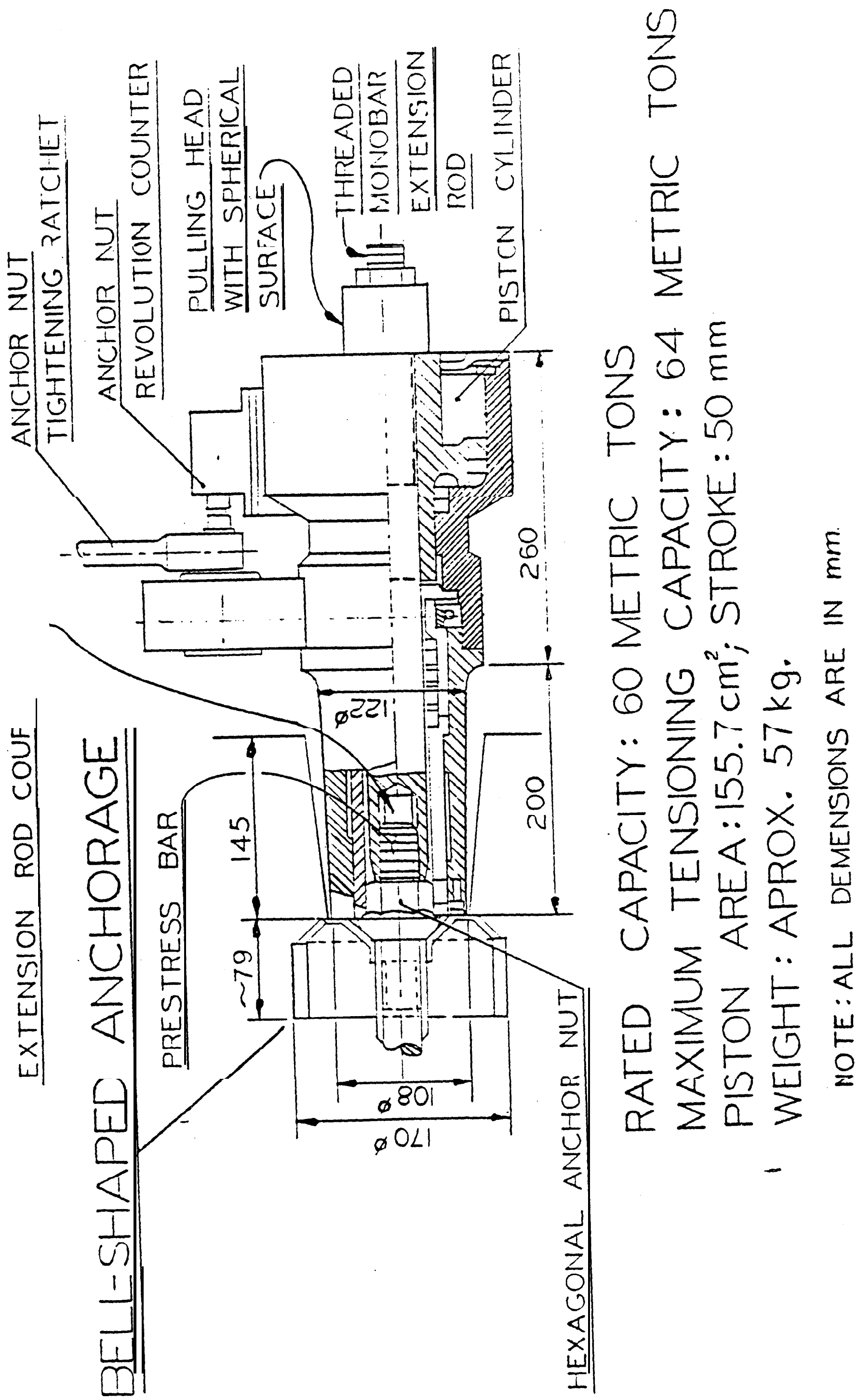


FIGURE 5 DYWIDAG 60 TON JACK

STRESSING

I. Preparation for Stressing Inspection

One of the most essential preparations for stressing inspection is the calculation of theoretical elongations due to jacking. Recommended practice is to calculate 80% of theoretical elongation, and to compare field measurements taken between 20% and 100% of jacking force. This should eliminate the effect of dead end seating loss, cable slack, and variation in the modulus of elasticity (E) of the strand at lower stress ranges. This is not a hard and fast rule. If variations are encountered or long cable lengths are to be stressed, one can base comparisons on a calculated 70% or 75% of the theoretical elongation.

It is the responsibility of the Contractor to submit elongation calculations as part of the working drawings. Structure Design and the Structure Representative then check the Contractor's calculations. Appendix D gives an acceptable method of calculating elongations as well as force factors.

Tendon elongations are calculated on the basis of an assumed modulus of elasticity (E) - usually 27,500 ksi for strand, The strand area is commonly assumed to be 0.153 square inches. The actual E and cross-sectional area (A) will be shown on the-materials release tag for the prestressing steel and the elongations should be recalculated to be consistent with those figures, In other words, actual E and A must be used to calculate elongations. However, do not recheck the minimum required area (A) based upon the actual values. Often packs of strand arrive with varying E and A. In this case, it is best to separate the strand so that all strand in a given tendon are the same. However, if the variations are small, tracking the varying strands in each tendon and using an average E and A is acceptable. Appendix D gives examples of elongation calculations.

Prior to stressing, it is also necessary to make preparations for monitoring the jacking force. The Standard Specifications (Section 50-1.08) require the Contractor to have an accurate load cell or pressure gage on each jack and that the jack/gage combination be accompanied by a certified calibration chart. Recertification should be done at least every 12 months. The Contractor's jack and gage are usually monitored by State pressure cells during stressing. Up to date information regarding jack calibration is available by accessing the Structure Construction computer bulletin board.

The Engineer in charge of field inspection of stressing should be familiar with the calibration chart and pressure cell prior to stressing. Appendix B gives instructions in the use and care of the pressure cell and Bridge

Construction Records and Procedures Memo 160-3.0 gives administrative instructions relevant to the pressure cell.

II. Field Inspection

The practice of stressing both simple span and some continuous structures from one end only is allowed only when shown on the contract plans or specifications. When two end stressing is required, the Contractor must stress both ends to $\mathbf{P_{jack}}$ either simultaneously or non-simultaneously and show the actual method of stressing on the working drawings.

In order to minimize the possibility of undesirable construction stresses, Standard Plan B8-5 states, " No more than l/2 of the prestressing force in any girder may be stressed before an equal force is stressed in the adjacent girders. At no time during the stressing operations will more than l/6 of the total prestress force be applied eccentrically about the centerline of the structure." However, please note that the l/6 factor is often modified for railroad structures.

If compliance with these requirements is overly difficult because of a particular tendon arrangement, Structure Design should be consulted.

In order to efficiently monitor stressing operations, a record in chart form must be kept for each tendon stressed. Figure 6 is an example of such a chart. Note that some of the information shown can be entered prior to stressing.

STATE OF CALIFORNIA

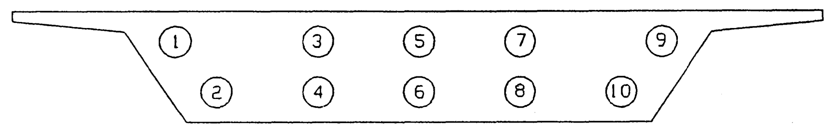
DEPARTMENT OF TRANSPORTATION

Br. Name ____________

Br. Number ____________

Contract # ____________

Date Tendons Placed ____________



Stressing Sequence										
Tendon Number										
Jack & Gage No.										
Date Str. / Initials										
Date Gr. / Initials										
P_j / No. of Strands										
Gage @ P_j										
20% P_j / Gage										
Meas. Elong. @ P_j -¼" [1]										
Meas. Elong. @ 20% P_j [3]										
Elongation (ΔL)										
Meas. After Seating										
Anchor Set										
Total Meas. Elong. [2]										
Theor. 80% Elong.										
% Dev. From Theor. (±)										

Notes:
1. Subtracting ¼" from the measured elongation is due to the strand elongation inside the jack. This is calculated by multiplying 1/12 inch per foot of strand between the anchor and pulling wedges at P_{jack}.
2. For two end streessing, use a second form for the second end. Summarize the data in the last three lines on one of the two forms.
3. For non-simultaneous two-end stressing, the anchor load will be in excess of 20% P_j at the second end. However, it is suggested that the measurement be taken at 20% P_j to be consistent.

FIGURE 6 CHART TO MONITOR STRESSING OPERATION

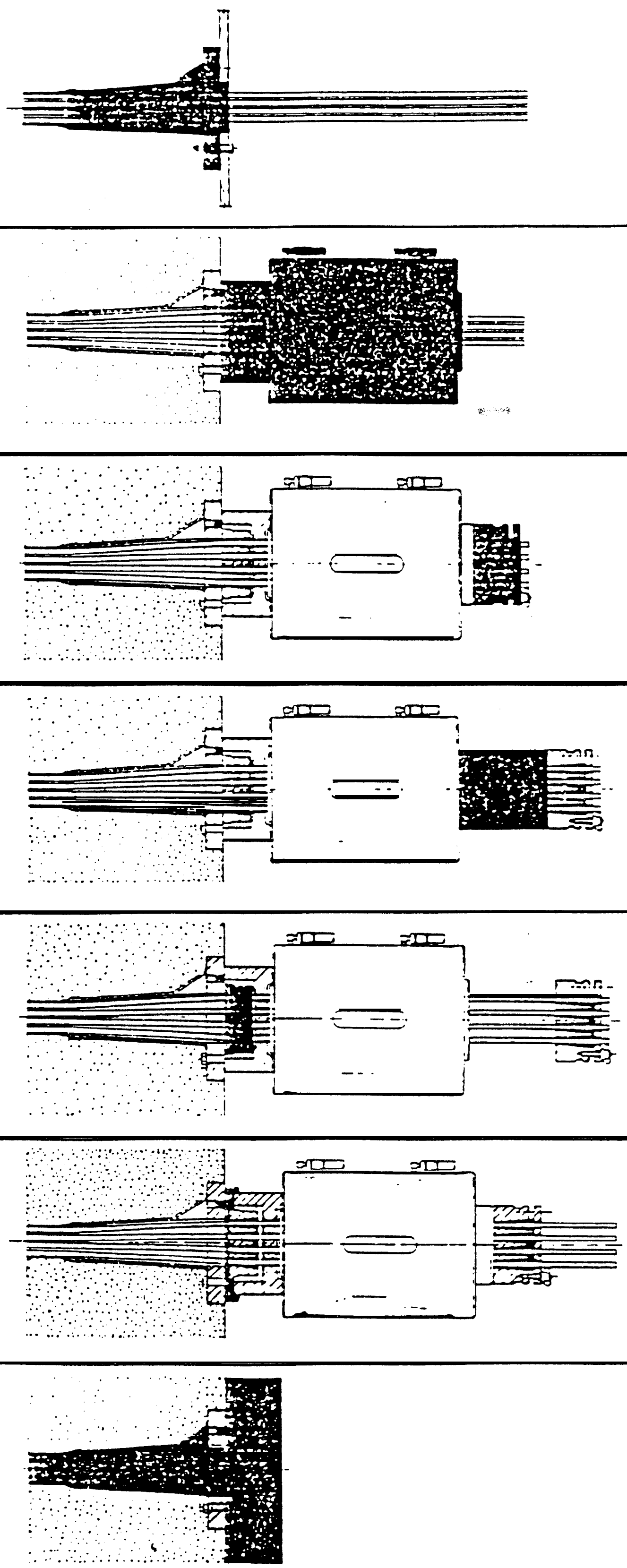
Remember, that this form is a guide. You may desire to custom design your own chart.

Each individual strand should be marked or painted at both ends of the structure to measure elongation and check for slippage. Tendons should be checked during and after stressing for any strand slippage or dead end seating loss, The area of l/2" prestressing strand typically varies between 0.151 and 0.154 square inches. However, some strand has been received with an area as small as 0.149 square inches. Such small strand has presented problems with proper seating of the wedges, Particular care should be used when stressing any strand with an area below 0.151 square inches. With the Dywidag bar system, the elongation can also be monitored by counting the turns of the anchor nut during stressing.

An important requirement of prestressing inspection is obtaining the anchor set shown on the plans. Anchor set is the amount of strand movement at the time of force transfer to the bridge. This is usually 3/8" for continuous structures and per shop plans for simple spans. In most prestress systems, elongation of the tendon occurs within the jack itself. At 0.75 f'_s, the tendon elongates approximately l/12" per foot of jack measured from the anchorage to the pulling head. When measuring or computing anchor set, do not include this jack elongation. Refer to

Appendix D for calculating the effect that anchor set has on tendon stress. For a complete jacking sequence including anchor set, see Figure 7, which is provided by the VSL Corporation.

It is the policy of Structure Construction that the pressure cell be used at the start of stressing to verify the Contractor's calibration chart and at least one calibration curve be made per structure or frame, The Structure Representative may require additional monitoring as needed. Figures 8 and 9 are examples of completed forms DS-C 86 and 86A for recording the Contractor's gage readings versus pressure cell readings. These forms shall be submitted upon completion to Structure Construction in accordance with Bridge Construction Records and Procedures Memo 3-1.0. See Appendix C for a complete inspection checklist.



Phase 1

■ Bearing plate with sleeve is attached to formwork ■ Either rigid tubing without strands or flexible tubing containing strands is placed.

Phase 2

■ After curing of concrete, formwork is removed from anchorage zone ■ Strands are drawn through duct if rigid tubing is used ■ Anchor head and grippers are fitted ■ Center-hole jack is placed over strands.

Phase 3

■ Pulling head is fitted. If required, a load cell can be placed between pulling head and jack piston.

Phase 4

■ Tendon is stressed ■ Pressure gauge reading and cable elongation are recorded.

Phase 5

■ Jack piston is retracted ■ Force is transferred to the structure through anchorage.

Phase 6

■ If required, a shim can be placed between anchor head and bearing plate to compensate for anchorage take-up of ¼".

Phase 7

■ Stressing equipment is removed ■ Projecting strands are cut off and anchorage sealed ■ Cable is grouted, if required ■ Anchorage is capped with concrete.

FIGURE 7 COMPLETE JACKING SEQUENCE

DEPARTMENT OF TRANSPORTATION

JOB STAMP

PRESTRESS CALIBRATION MONITORING SHEET

04 - SC1 - 85 - 3.0/5.3
04 - 123454
Wide River Bridge

DS-C86 wp50

DATE: 08 - 31 - 90 STR. REPRESENTATIVE: Joe Bridge
NAME OF SYSTEM: VSL INSPECTOR(S): I. Girder, T. Beam, I. M. Lost

JACK NUMBER: 6 - 1O - 43
GAGE NUMBER: 6 - 1O - 43 B
FOR 1/2" 270 KSI STRAND ABSOLUTE MAX..Pj=31 Kip/Strand X #Strands/Tendon: ______ = 31 Kips X 48 = 1488 K
FOR 0.6'" 270 KSI STRAND ABSOLUTE MAX..Pj=44 Kip/Strand X #Strands$Tendon: ______ = 31 Kips X = ______
CONTRACT REQUIRED ....Pj = 1488 K

Theoretical Maximum Gage Pressure:-........ $= \frac{Pj}{\text{Ram Area}} = \frac{1488\ K}{179.1\ in.^2} = 8308$ psi

Maximum Gage Pressure From Latest Contractors Calibration: 8750 psi
Strain Gage Indicator CHC 13686
Electro Hydraulic Cell Number: 18 Numerical Display Setting: 1094 , Actual Gage Factor: O-72
Measurable Elongation = 80% Total theoretical ELongation: 28.5"

Gage Reading	Load from Indicator		Load from Calibration Chart				Remarks
1680	297		300				20% P,
2000	352		350				
3000	523		520				
4000	692		690				
5000	855		855				
6000	1025		1025				
7000	1198		1195				
8000	1365		1360				
8720	1488		1480				Meas E long = 29"

FIGURE 8 SAMPLE FORM DS-C86

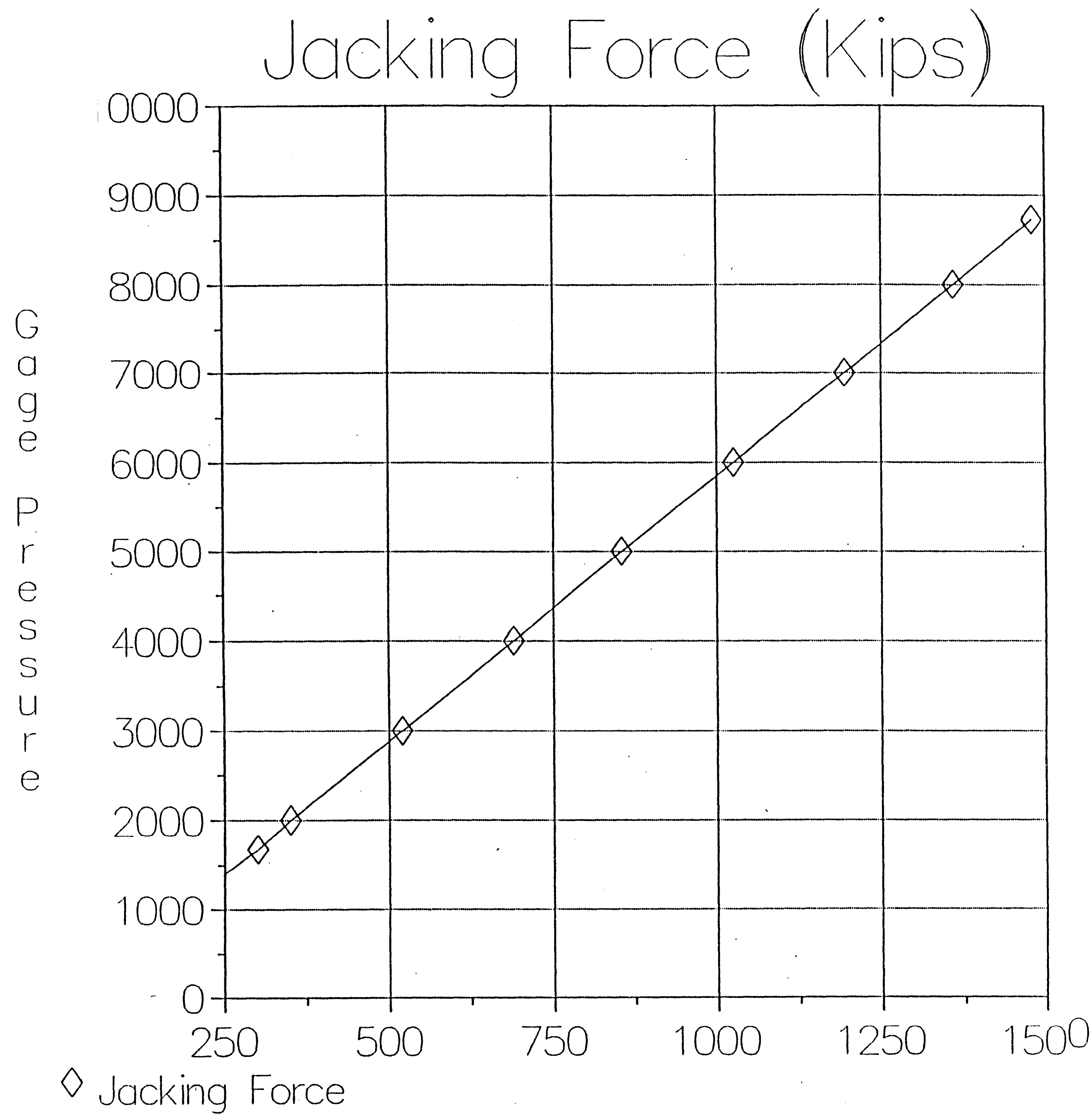


FIGURE 9 DS-C86A

III. Overstressing of Prestressing Steel

Technically, prestressing wire and strand develop high strength and excellent creep characteristics through cold drawing. During this cold drawing process the grain structure is elongated and aligned into a condition resulting in specific physical and mechanical properties.

The three stress-strain curves shown in Figure 10 show a 1/4" cold drawn, stress relieved prestressing wire tendon that had been stressed to 83% of the minimum ultimate strength of the wire.

Note the great difference in the stress-strain relationship between Sample #1 and Samples #2 and #3, keeping in mind that all three samples came from the same tendon. The illustrated variations in physical properties of wire stressed above the proportional limit is one reason that the Standard Specifications do not permit stressing beyond 75% of the specified minimum ultimate strength.

Due to the possibility of wires or strands being of unequal length within a tendon, some of the wire or strands could be stressed to their yield strength, even when the tendon is not overstressed. Therefore, when the jacking force exceeds the 75% limitation, some of the wire or strands in the tendon may be seriously overstressed. This condition is demonstrated by the stress-strain curve for Sample #1 in Figure 10.

When steel such as prestressing wire or strand is stressed beyond its elastic limit or yield strength, some of its physical characteristics change. The most significant changes are in the modulus of elasticity (E) and the creep rate. If these properties are changed by permanently overstressing, the significance of elongation measurements is questionable. Remember, if it appears that the 75% limit is being exceeded - - stop!

The effect of permanent overstressing on physical properties of strand has been demonstrated by laboratory tests in a 100 ft. pretensioning bed as follows:

Initial Jacking Force	Initial percent of Ultimate	Residual Stress @ 72 hrs	Percent Stress Losses @ 72 hrs
34 kips	82.3	26 kips	23.5
28 kips	67.8	27 kips	3.6

This example indicates that strand when kept in an overstressed condition (greater than 0.75 f'_s) results in a significant reduction of prestressing force due to the change in creep properties of the strand. This is one reason why the maximum anchor stress may not exceed 70% of the ultimate strength of the steel, and the jacking force must not be exceeded.

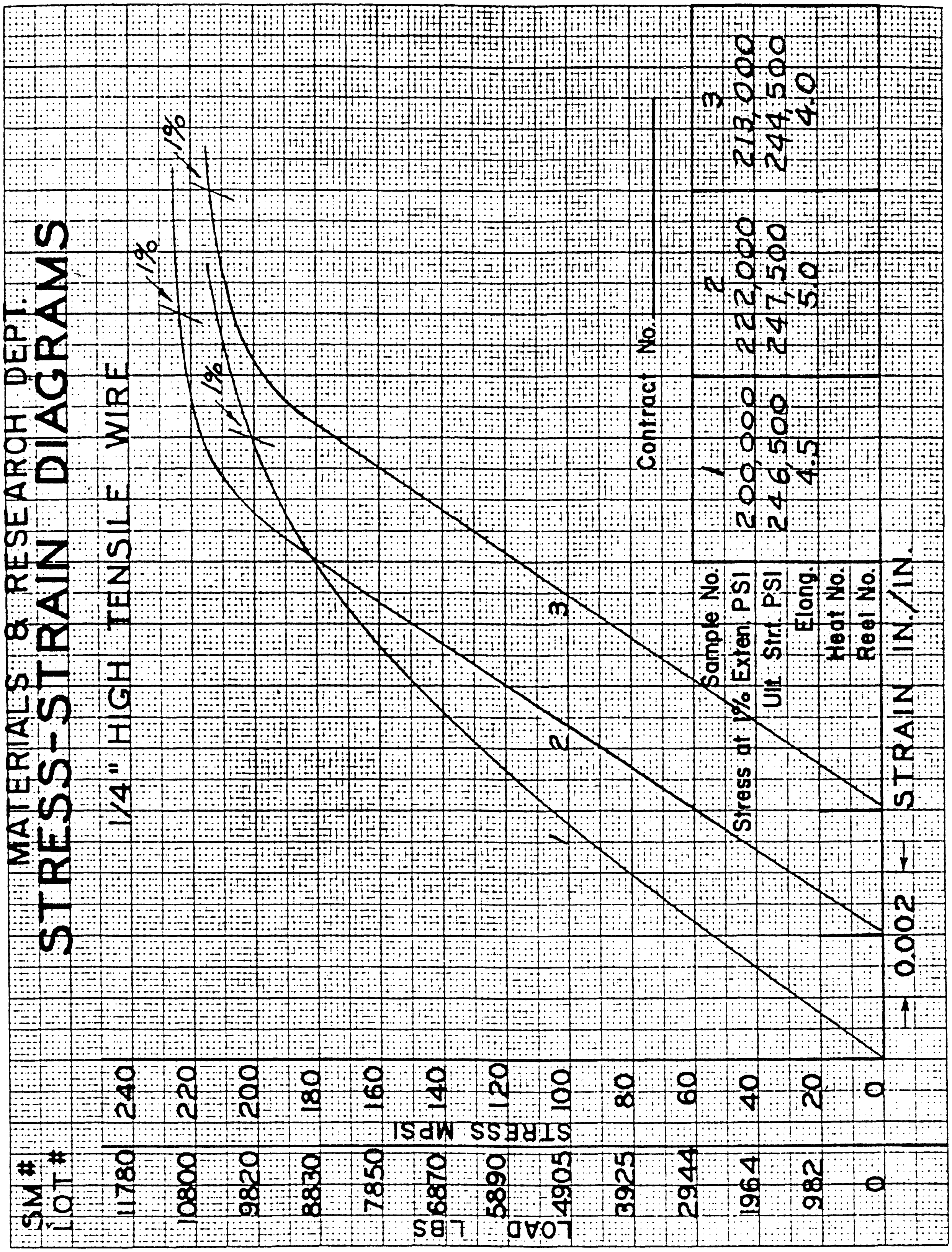

MATERIALS & RESEARCH DEPT.
STRESS-STRAIN DIAGRAMS
1/4" HIGH TENSILE WIRE
Contract No.
Sample No. 1 2 3
Stress at 1% Exten. PSI 200,000 222,000 213,000
Ult. Str. PSI 246,500 247,500 244,500
Elong. 4.5 5.0 4.0
Heat No.
Reel No.
1%
→ 0.002 ← STRAIN IN./IN.
SM #
LOT #
STRESS MPSI
240 220 200 180 160 140 120 100 80 60 40 20 0
LOAD LBS
11780 10800 9820 8830 7850 6870 5890 4905 3925 2944 1964 982 0

FIGURE 10

IV. Elongation

The measured elongation should substantially agree with the calculated elongation. Since the last edition of the California Prestress Manual, the friction coefficent has been reduced to 0.20 and the wobble correction has been eliminated. However, due to variations in friction factor, elongations tend to run higher than calculated, often by 5% to 10%. This is acceptable as long as the variations are understood and explained; but deviations between elongations of similar tendons of the same bridge should not vary more than 4% +/-. Remember, each case must be carefully examined to assure compliance with the working force required.

The following are possible reasons for elongations not being within the calculated range:

1. Incorrect number of strands placed in the tendons,
2. Excessive wobble of ducts increases friction and decreases elongation.
3. Unusually smooth duct placement decreases friction and increases elongation.
4. Even, layered strand placement reduces friction and increases elongation, particularly when strand are 'pushed' into the duct.
5. A change in jack efficiency is not detected by a pressure cell. This may cause faulty readings.

6. Elongation calculations may be wrong due to the following:

   a. Incorrect Modulus of elasticity (E) or area of strand (A).

   b. Incorrect or varying tendon lengths due to skew or sharp radii.

   c. Differing coefficient of friction between girders on sharply curved structures.

   d. Different tendon paths in a girder.

7. Incorrect method of measuring elongations.

8. Slippage of strand during stressing, especially if the strand area is small (below 0.151 sq. in.).

9. Gage damaged or indicator not zeroed.

The cause of any inconsistent elongations among the tendons of a structure must be determined as soon as possible. Do not cut off excess strand until the problem is resolved. In the event it is necessary to detension a tendon, stressing contractors must have suitable equipment available for this purpose as required by the TransLab approval procedure.

As a general policy, strand <u>should not</u> be cut off until all tendons in the structure are fully stressed.

GROUTING

Grouting of post-tensioned structures has a dual purpose:

1. to protect the strands from corrosion and slippage,
2. to develop the required ultimate moment capacity of the structure.

Effective checking of ducts for blockages and damage prior to stem and deck pours is described in this manual under "Rigid Duct". This check is necessary to assure a successful grouting operation. Be sure also to read the provisions of Section 50-1.09 of the Standard Specifications. Additional information on grouting is provided in Bridge Construction Records and Procedures Memo 160-4.0.

Grouting material consists of Type II Modified Cement mixed with not more than 5 gallons of water per sack of cement. Be sure to check the Contractor's gage or calibration marks to assure compliance with this 5 gal./sack maximum. The addition of admixtures, such as Interplast C, is optional, but must be approved by the Engineer (See Std. Spec. 50-1.09). Admixtures, if used, are generally designed to increase or sustain the fluidity of the grout and may become necessary in order to comply with the maximum water requirements.

The grout mixture should be checked in accordance with California Test No. 541 (See Appendix E), This test is required as a check at both the inlet and outlet ends, The flow cone is plugged, plumbed, and filled with a known quantity of grout,, Then the time required to empty is measured with a stopwatch which reads to the nearest 0.1 second or less (a minimum efflux time of eleven seconds is required). A record should be kept of test results. The twenty minute quiescence test should also be performed when appropriate. Remember that this and all other equipment must be cleaned and maintained regularly. Information regarding grouting and grout testing can be found in Bridge Construction Records and Procedures Memos 160-4.0 and 160-5.0.

While the specifications do not currently establish a maximum efflux time, a test resulting in excess of fifteen seconds may be undesirable as this increases the chances of a stoppage. A slow efflux time can be attributed to several possible problems: 1) loss of water in the equipment due to poor seals, hose connections, etc., 2) hot weather conditions, 3) insufficient mixing time, 4) hot cement or old cement.

The water cement ratio must not be increased to accommodate grouting. If this is a problem, try to detect and correct the problem before proceeding. Also, be sure to receive a certificate of compliance for the cement used.

Equipment used for grouting is generally at the option of the Contractor. However, the specifications do require equipment capable of grouting at least to a pressure of 100 psi, a pressure gage having a full scale reading of not more than 300 psi, and standby flushing equipment provided on structures requiring duct vents. Also a screen with .07" maximum clear openings (approx.

14 mesh) must be used prior to pumping to eliminate lumps and foreign material. Grout must be continuously agitated during pumping.

PHOTO 9
GROUTING EQUIPMENT

Under current specifications, flushing of prestress ducts prior to grouting is the option of the Contractor. It is recommended that flushing of strand systems be discouraged under normal conditions. In some structures, particularly those with large ducts, it is extremely difficult to completely remove all flushing water. The entrapped water evaporates leaving a void which prevents bonding of the prestress steel and enhances the chances of rust. On the other hand, it is preferable to flush the monobar ducts just prior to grouting to improve-groutability in the restrictive space between bar and duct. The quantity of entrapped water is minimal.

Couplers pose a grout problem inherent to bar systems. If care is not exercised when positioning them in their enlarged duct housing, they can jam against the housing during stressing. If this occurs, it not only produces an incorrect stress distribution in the bar, but also seals the duct. Preflushing or blowing air through the ducts after stressing are a means of discovering blockages.

An inspection checklist for the grouting operation is available in Appendix C.

Blockage or leakage of a duct during grouting of tendons with strands has become less common since the advent of rigid ducts. However, in the event of blockage or leakage, it is the responsibility of the Contractor to propose and execute a successful solution. Attempting to grout a blocked duct by simply injecting grout from both directions is unacceptable as this tends to create a pocket of compressed air in the duct. Building up the grout pressure to free a blockage may also be detrimental as the pressure forces out water and the cement particles can form a plug which cannot be removed by flushing or blowing with air.

Upon grouting a tendon, it is necessary to see that the outlet valve is closed before the inlet valve. Remember, positive shutoff valves are required at injection pipes. Vents and ejection pipes also are required to be fitted with valves capable of withstanding the pumping pressures. Prior to closing the outlet valve, the wasted grout should be checked for equivalent consistency, especially in the case of ducts that had been previously flushed with water, Care should be taken with the wasted grout; avoid running grout into pervious backfill, traffic, structural or highway drainage, etc. Discuss where the wasted grout will be disposed and how any mess will be cleaned up with the Contractor prior to beginning grouting.

APPENDIX A - PRESTRESSING SYSTEMS

I - NEW SYSTEMS

The following checklist includes the minimum required information necessary for approval by the Transportation Laboratory of a new or modified post-tensioning system:

All prestressing systems that are proposed to be used in the State of California shall be submitted in the following form to expedite approval of the system or systems.

Seven copies of the final submittal are required by Caltrans and shall be bound or stapled together with a title page indicating the name or names of the systems being submitted. The individual numbered sections shall be tabbed and listed in the following order:

1. DESCRIPTION
   - a. Current product description literature of the system or systems being proposed.
   - b. Prior listing of the system. Include specific details of projects where it has been used.
   - c. Complete records of tests run on the system independent of Caltrans' witness tests.
   - d. Explain how seating loss is to be controlled and measured.

2. HARDWARE

   a. Anchor head.

      1) Detailed drawing.

      2) Mill certificates - showing material composition, strength and manufacturer.

      3) Quality control document

   b. Bearing Plate

      1) Detailed drawing.

      2) Mill certificate.

      3) Quality control statement.

   c. Wedges or Nuts

      1) Detailed drawing.

      2) Mill certificate,

      3) Quality control document.

   d. Trumpet detail drawings.

3. CALCULATIONS

   a. Stress behind bearing plate at service load after losses.

   b. Stress behind bearing plate at 95% specified ultimate tensile strength.

   c. Maximum bending stress in bearing plate of 95% specified ultimate tensile strength.

4. SYSTEM

   a. Detailed drawings of the anchorage system, jacking system, duct and grouting details.

b. Complete information on grouting procedures and equipment to be used,

c. Description of how system components are protected from physical damage and corrosion.

d. Description of tendon repair or replacement should a failure occur,

e. Description of how qualified technical assistance is provided in the field for the Contractor performing the work.

II. - PRESENTLY USED SYSTEMS

Following is a summary of the State approved prestress systems. The summary is considered complete and includes both systems used in bridges and as tieback anchors. However, it should be remembered that new developments in the prestress industry necessitate change. Therefore, the various systems may revise capacities, improve anchorages, develop new jacks, etc. Of course, changes such as these may void prior system approval. Many of the companies also have system capabilities (smaller and larger) which have not been approved for State use. Both the Sacramento HQ TRANS LAB and the Division of Structures Prestress Committee have current files for all approved systems. Check the Structure Construction Bulletin Board for a current list of those contractors with currently approved systems.

APPENDIX A - PRESTRESSING SYSTEMS

AVAR Construction Systems. Inc.

The AVAR System utilizes 0.5" strand anchored with split wedges at both the anchor plate and the pulling head. AVAR presently uses anchorage systems utilizing 3, 4, 5, 7, 12, 22, and 34 stands maximum. Note Load Cell between stressing head and center hole ram.

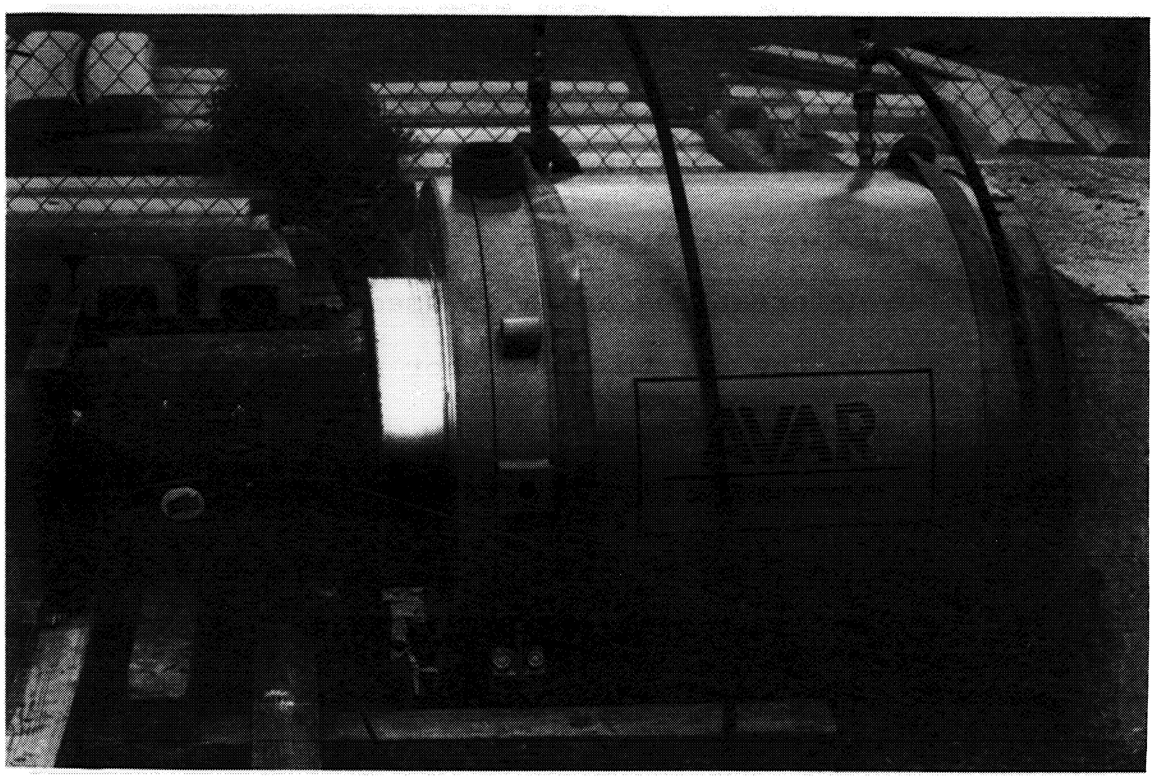


PHOTO 10
PHOTO BY AVAR CONSTRUCTION SYSTEMS INC.

Dywidag - DSI (Dyckerhoff and Widmann, Inc.)

Dywidag systems include both deformed bar and strand systems. The Dywidag threaded bar prestressing system was developed in Europe. It's use, including a broad application as a rock anchor, has greatly expanded in this country since its introduction a decade ago. The bars have cold-rolled, thread-type deformations continuous along two opposite sides of the bar. The continuous deformations are especially adaptable to segmental construction. The bars can be cut to any length to fit field conditions and yet retain a threaded end for splicing or anchoring. Splicing is performed very simply with threaded couplers. The deformations are also used to transfer the prestress load in the bar to the anchor nut, and to bond the bar to the structure when grouted.

The bars are available in various diameter sizes. They may be used as a single tendon (monobar) or in multiple groups. State approved applications use l", l-1/4" or 1-3/8" monobar. A bell-type anchorage is normally used with the monobar. The bell consists of a steel cylindrical section with a thin steel plate attached to one end. The principle behind the design of the anchor is to confine concrete within the cylinder and let the confined concrete transmit the majority of the anchor load to the structure.

Stress is applied with small, portable jacks which can be handled by one or two persons. The jacks contain a ratchet assembly which is used to advance the hex anchor nut when stressing the bar. The smaller size jack, although rates at 60 metric ton, has the capacity to stress the l-1/4" bar to 75% ultimate. The larger jack, rated at 110 metric tons, is more rugged and is used for difficult conditions. (Metric ton equals 2204 lbs.)

Dywidag strand systems typically use 0.6" strand for 4 strand to 27 strand tendons. A 31 strand tendon is also approved using 0.5" strand.

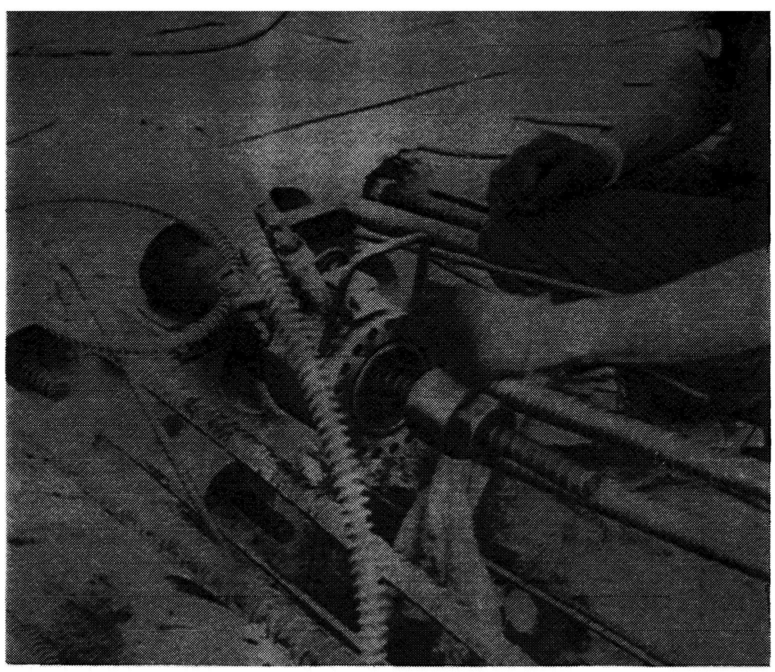


PHOTO 11
DYWIDAG'S 60 - TON MONOBAR JACK

PHOTO 12
MONOBAR ANCHORAGE

APPENDIX A - PRESTRESSING SYSTEMS

Stresstek System

Stresstek is not currently (9/91) active on State projects, but is an approved system. Stresstek anchors individual 1/2" strands with a pair of split wedges at the anchor plate and three piece wedges in the pulling head. Individual strands are placed in a strand guide which is inserted into the center hole of the jack. A manually operated device, either mechanical or hydraulic, is used to initiate seating of the permanent wedges.

Anchorage systems presently used are capable of holding a maximum of 13, 19, or 31 strands, Also approved are the Stresstek 0.6" strand systems using 4, 7, 13, or 19 strands maximum.

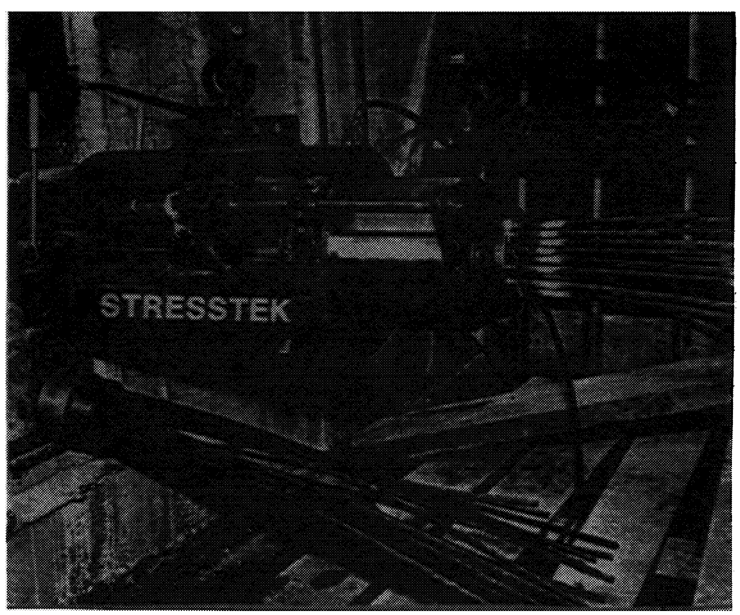


PHOTO 13
19 STRAND STRESSTEK JACK
(Photo by Stresstek)

VSL System

The VSL System uses individual l/2" strands anchored with pairs of split wedges at the anchor plate and three part wedges at the pulling head. VSL presently uses anchorage systems capable of holding a maximum of 1, 4, 7, 12, 19 24, 27, and 31 strands, The anchor set is determined by the head space between the anchor plate and jack. A 4 strand system utilizing 0.6" strand has also been approved for use on State projects.

PHOTO 14
31 STRAND VSL JACK

VSL has also developed a flat duct system which makes use of 4 parallel 0.5" strands all in one plane. The duct is longitudinally seamed, 2" round galvanized drain pipe that has been flattened to a 2-3/4" x 7/8" section. A special cast steel anchorage unit splays the strands to a 5" width and seats conventional VSL wedges. A highly portable lightweight (60#) monostrand jack is used for stressing.

A short plastic tapered section transitions the flat duct to the flat steel anchorage. A steel tension ring is inserted at the smaller end to confine the lateral forces caused by the splayed ends,

This system is especially useful for stressing thin slabs transversely.

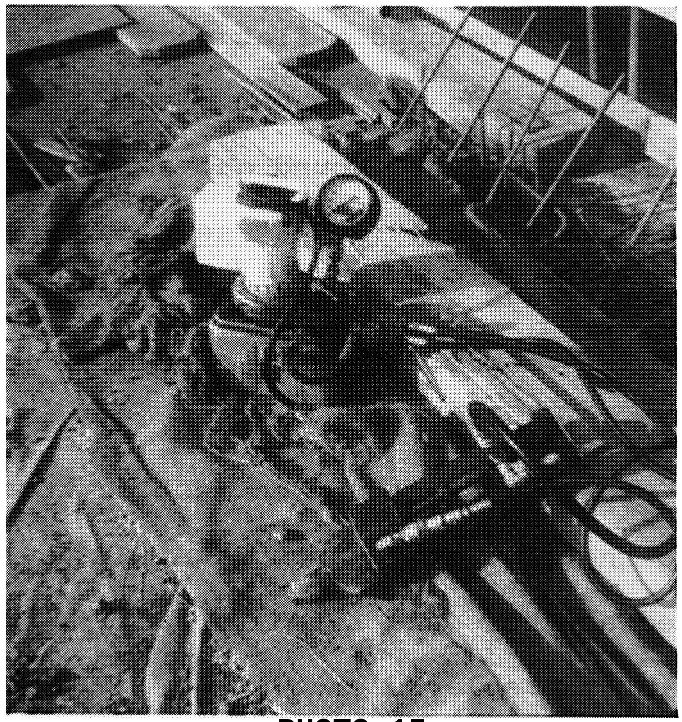


PHOTO 15
VSL MONOSTRAND JACK

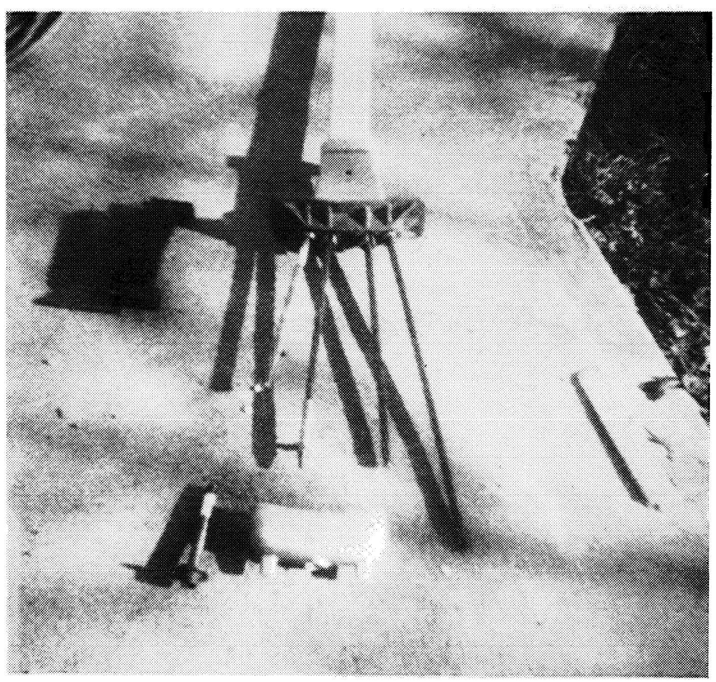


PHOTO 16
VSL FLAT DUCT ANCHOR

Western Concrete Structures System

Western Concrete Structures, Inc. is not currently active on State projects, but is an approved system, The Western Concrete System anchors individual l/2"' strands with pairs of split wedges at both the anchor plate and jack pulling head. Western uses a center hole jack with a strand guide permanently fixed in the center hole. A power seat is not available in this system to seat the wedges.

Anchorage systems presently approved are capable of holding a maximum of 1, 4, 12, 16, 20, 24, 28, and 48 strands.

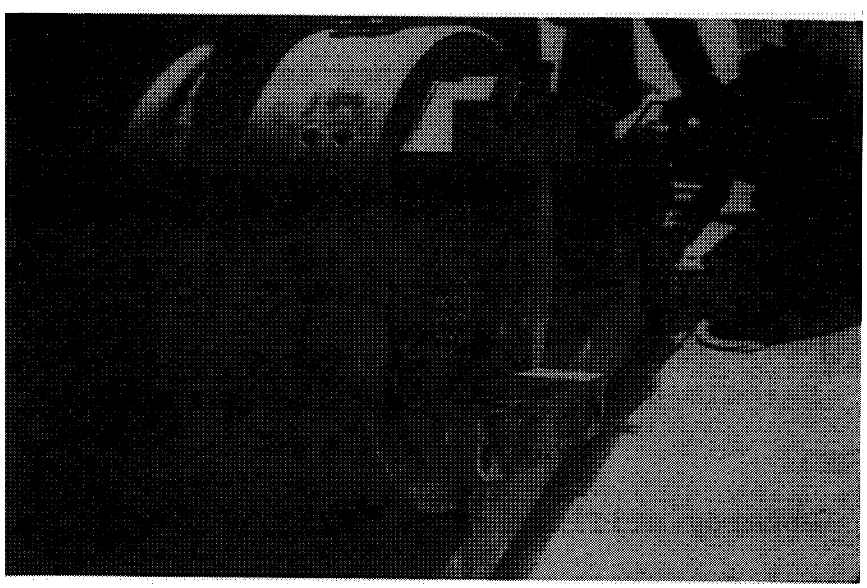


PHOTO 17
WESTERN'S 48 STRAND JACK

III. Soil Anchors

The use of soil anchors as tiebacks, tiedowns, and soil nails for both temporary and permanent work has become increasingly common. Section 9 of the Trenching and Shoring Manual contains information on the design and analysis of these systems for temporary work. Specifications for installation and testing of permanent anchors are contained in the contract Special Provisions.

The following approved post tensioning Contractors perform tensioning on soil anchors only:

Case-Pacific

Case-Pacific utilized other approved systems,

Foundation Constructors

Foundation utilizes other systems.

Mahaffey Drilling

Mahaffey also utilizes other systems previously discussed.

Malcolm, Drilling Co., Inc.

Malcolm also utilized other systems.

Pomeroy

Pomeroy utilizes other approved systems

Schnabel Foundation

Although not currently on the Translab active list, Schnabel is an approved Contractor, They utilize the LANG system which is approved for 0.6" strand with an anchorage capable of a maximum of 6 strands,

Wagner Construction

Wagner also utilizes other approved systems.

IV. STRENGTHENING

Strengthening of bridge structures provides another use for post-tensioning systems. This work usually consists of pairs of single strand tendons, one on each side of the girder to be strengthened. These tendons are then tensioned simultaneously and later grouted. As with all previously, described prestressing, only approved systems are to be used by approved contractors. Additional specifications will be found in the contract Special Provisions,

APPENDIX B - PRESSURE CELL

A pressure cell and transducer/strain indicator (see Photo 18) is a commercially made unit which accurately measures hydraulic pressure by converting changes in applied pressure into corresponding changes in output voltage. The pressure sensing element consists of a cell fitted with strain gages. The strain gages are connected to form a balanced Wheatstone Bridge, which responds to pressure changes by proportional changes in resistance. The change in resistance is measured with a transducer/strain indicator (see Photos 19 & 20). The indicator interprets the change in electrical resistance of the strain gage circuit in relation to the strain developed in the pressure cell,

Since the pressure in the, hydraulic system is proportional to the force exerted by the jack, the readout can be calibrated to read directly in kips rather than resistance or strain. Although this system gives accurate measurements of hydraulic pressure, it must be calibrated with a load cell for any given jack and gage combination at least once a year. During calibration, the load cell is placed either behind or in front of the jack (see Figure 4 on Page 25) enabling a readout of the actual force applied to the prestress steel. Load cells are calibrated with "National Bureau of Standards" load cell.

Readings should not be taken while the ram is retracting or in static condition as hysteresis will likely result in erroneous values. The calibration curves and pressure cell readings are only valid when the ram is extending.

Pressure gages are bourden tube-type with rack and pinion gear drive which accounts for part of the poor hysteresis curves. If there is any indication of damage to the gage, the stressing system should be checked with the pressure cell. If there is more than 3% difference between the pressure cell and the calibration chart, the jack and gage should be recalibrated. Usually the stressing Contractor has the jacks calibrated with several gages as a backup. Also, if the jack has been overhauled (new packing, machine work, etc.), it should be recalibrated.

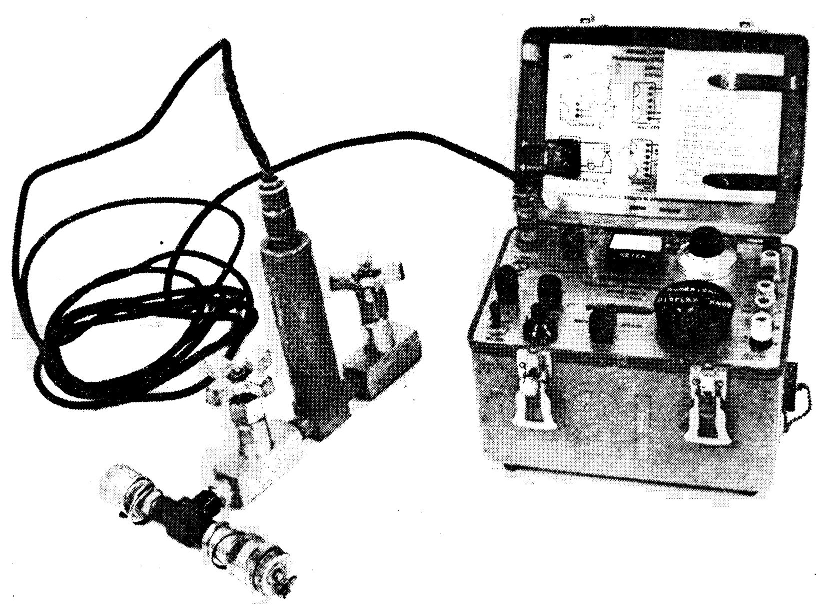


PHOTO 18
PRESSURE CELL AND TRANSDUCER/STRAIN INDICATOR

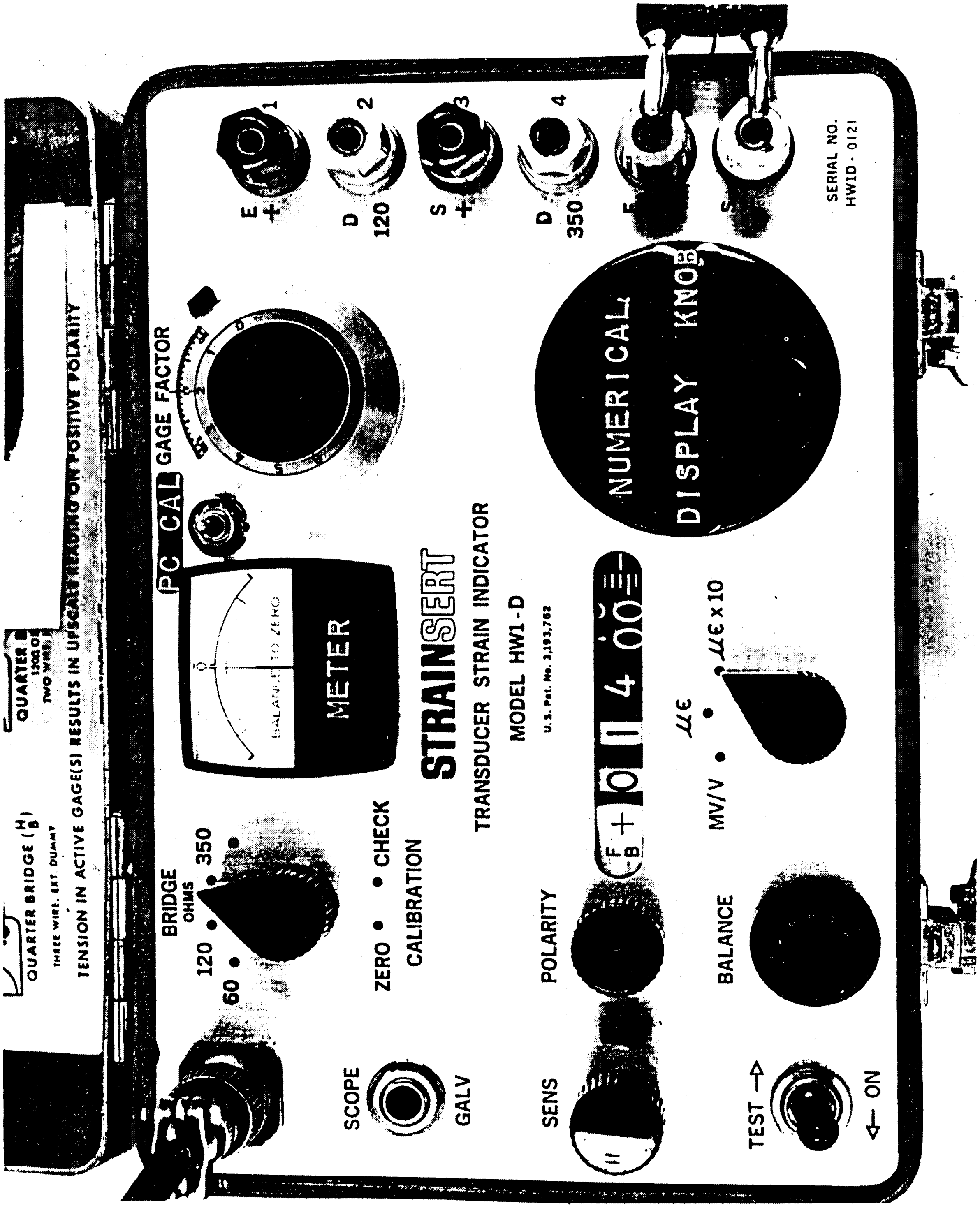


PHOTO 19
TRANSDUCER/STRAIN INDICATOR

APPENDIX B - PRESSURE CELL

Instruction for the use of the Pressure Cell: with meter

1. Place the Pressure Cell into the hydraulic system near the Contractor's gage.

2. Connect cell to indicator with 4 pin plug.

3. Turn toggle switch on.

4. Set controls (unless otherwise noted for particular jack).

Bridge	- 350 ohms
Readout switch	- E
Sens	- turn full clockwise
Polarity	- F/B +

5. Close check valve on pressure cell.

6. Open pressure release valve (bleed) on Pressure Cell.

7. Turn numerical display to zero (0000).

8. Set meter to zero with balance knob.

9. Turn numerical display to a setting for the particular jack being used. (See pressure cell display setting chart).

10. While depressing (PC) switch set meter to zero with gage factor knob.

11. Reset numerical display to zero.

12. Check meter for return to zero. If needle does not return to zero, repeat above procedure of calibration (steps 7-12).

13. After calibration is complete, close pressure release valve.

14. Open check valve.

15. Numerical display indicated load in kips, e.g. 2130=213 kips or 213,000 lbs. If set-up requires Ex10, 213=213.

16. Recheck zero after each run until assured zero setting is stable. This requires closing check valve and opening pressure release valve with numerical display set at zero (0000).

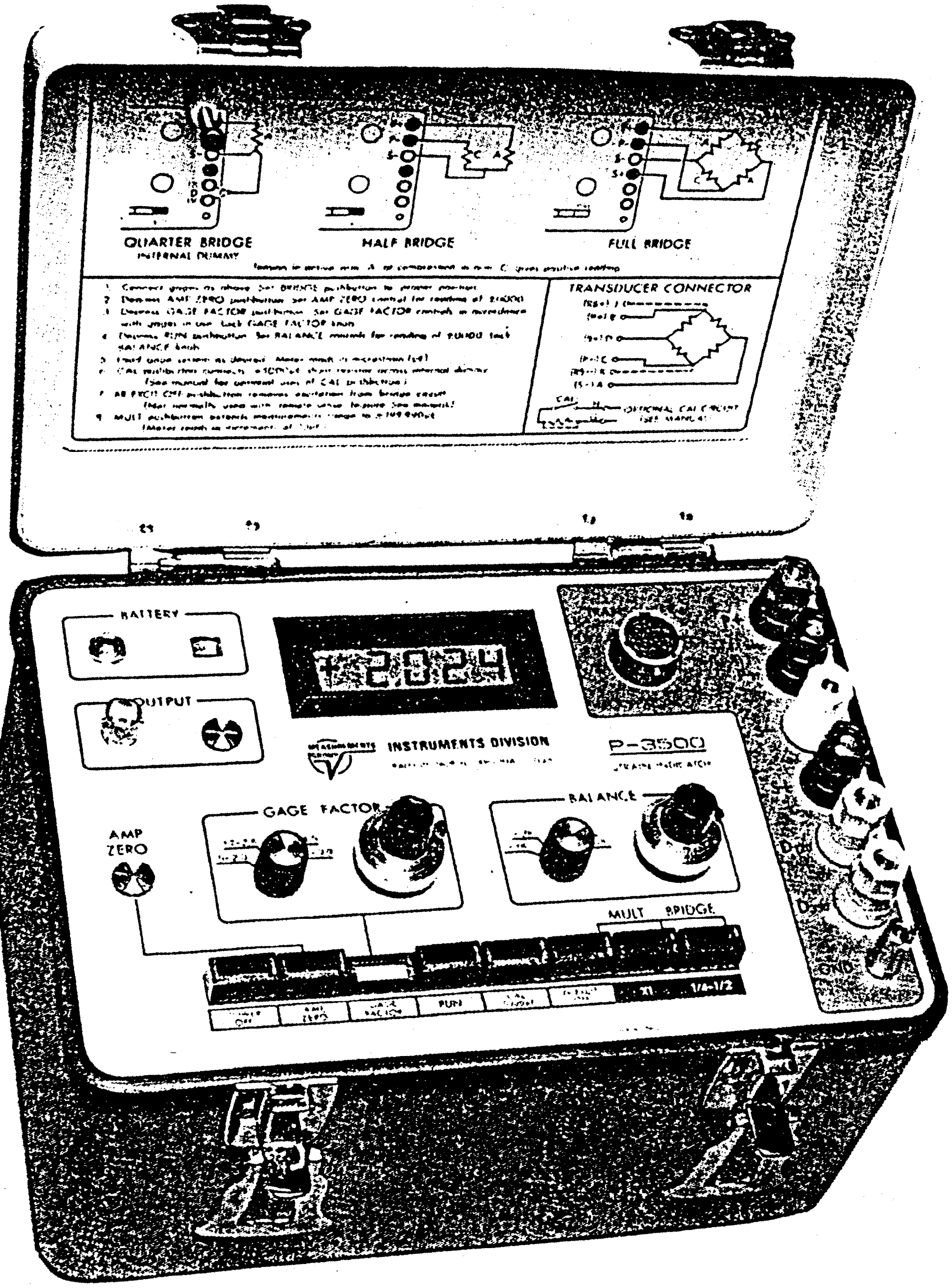


PHOTO 20

MODEL P-3500 STRAIN INDICATOR

APPENDIX B - PRESSURE CELL

Instruction for the use of the Pressure Cell: with digital display

1. Place the Pressure Cell into the hydraulic system near the Contractor's gage.

2. Connect cell to indicator with 4 pin plug.

3. Turn toggle switch on.

4. Select FULL BRIDGE (button at right end of switch bank). Battery should be charged prior to use. Check battery indicator (needle should be in the white area).

5. Depress Gage Factor switch and adjust for gage factor setting from pressure cell display setting chart, change range selector switch if setting cannot be reached by adjusting gage factor Pot.

6. Close check valve on pressure cell.

7. Depress RUN switch and adjust balance pot for zero reading, the reading may fluctuate slightly about zero, set as close as possible.

8. In RUN mode move the spring loaded P.C. switch UP or DOWN and hold to apply calibration resistor to circuit and adjust gage factor pot to obtain numerical display setting from chart.

9. Release P.C. switch and check for zero balance, adjust BALANCE pot if necessary, repeat step 5 and then check zero again.

10. After calibration is complete, close pressure release Value.

11. Open check valve.

12. Numerical display indicated load in kips, e.g. 2130=213 kips or 213,000 lbs. If set-up requires Exl0, 213=213.

13. Recheck zero after each run until assured zero setting is stable. This requires closing check valve and opening pressure release valve with numerical display set at zero (0000).

Check list for malfunctioning Pressure Cell:

A. Cell indicator will not balance. Possible causes:

1. "Low" battery
2. Cell not properly plugged in
3. Indicator not turned on
4. Loose connections
5. Severed or damaged lead wire
6. Connections wet and/or muddy
7. Cell wet and/or muddy
8. Resistor is plugged in (older indicators only)
9. Broken resistor
10. Pressure applied to cell

B. Gage factor has large change. Possible causes:

1. Incorrect PC resistor setting
2. Poor connection to cell
3. Wire or cell damaged
4. Cell is wet or damp
5. Malfunction of indicator electronics

C. Needle jumping or erratic. Possible causes:

1. Tendon friction in structure causing erratic load changes.
2. Static from motors or pumps - to alleviate, plug in ground wire.
3. A short or poor connection - connect white terminal to ground.
4. Hydraulic surge - keep gage connections away from pump
5. Local Radio stations,
6. Contractor's generators.

D. Needle sluggish or will hardly move. Possible causes:

1. Pressure cell not plugged in
2. Low battery
3. Water on connections or cell
4. Broken or damaged connection cable

If the malfunction cannot be solved in the field, consider the cell and/or indicator unsatisfactory for use.

Maintenance of the Pressure Cell:

1. Keep all components dry and clean. Do not oil or clean with solvents; wipe with clean cloth.

APPENDIX B - PRESSURE CELL

Maintenance of the Pressure Cell:

1. Keep all components dry and clean. Do not oil or clean with solvents; wipe with clean Cloth.

2. Keep the battery charged, but do not over charge.(8 hrs max)

3. Remember that the pressure cell and readout box are delicate instruments and should be treated as such. (Eg. Do not transport equipment in bed of truck.)

APPENDIX C - INSPECTION CHECKLIST

Prior to start of field work:

l. Remind the Contractor of his responsibility to submit shop plans, calculation sheets, and notice of material sources in a timely manner.

2. Review working drawings:

   a. Check tendon paths and Contractor's corresponding calculations. Calculate ordinates at enough points to produce a smooth path.

   b. Compare physical layout of end anchorage details on shop plans with details shown on Contract Plans and B8-5 of the Standard Plans.

   c. Rough check length of tendons or rods as calculated by Contractor,

   d. Review stressing sequence and locations of stressing operation shown on working drawings.

   e. If blockouts extend beyond the face of abutment, additional steel may be required. Also, special attention should be given to the support of the blockout concrete.

   f. Check for possible- conflicts with ducts at columns, caps, abutments, and hinges, due to reinforcing steel, hinge restrainers, utilities and deck drains.
   Use 18" x 48" template behind bearing plate to check for obstructions.

g. Check to see if additional rebar or changes in concrete dimensions will be required to accommodate the Contractor's system. Such details should be included on the shop plans.

h. Skewed structures require additional investigation.

i. Check elongation calculations.

j. Concur with Structure Design on working drawings.

k. Contractor should provide V.P.I. powder information.

3. Make sure everyone concerned (Design, Structure Representative, Contractor, Subcontractor) are working from the approved working drawings.

When prestress materials arrive at jobsite:

1. See that material has been released and physically identified by State Transportation Lab (white and green sheets). Record the (A) and (E) of the strand. Collect the release tag to coincide with the TL-29, Do not remove all of the release tags.
2. Check condition of packs.
3. Scan material to see that it is what contract and working drawings call for by number, size, length, etc.
4. Determine if required rust inhibitor agent (VPI, etc.) has been applied to stress steel - check for rust.
5. Check condition of ducts thoroughly.
6. Check storage site for adequate protection of materials.

Bearing plates and trumpets:

1. Check that the blockouts are formed to correct slope/batter. Use alignment tool to check if bearing plates are perpendicular to the ducts.
2. Make certain anchor plates are the correct size.

3. Check that the trumpets are properly secured to, the bearing plates,

Placement of rigid duct:

1. Check adequacy of end anchorage form work. Check the size of anchorage hardware. Plates should be fastened to the forms at the proper angle, grout tight, and secured.

2. Make sure each girder contains the correct number of ducts. And that the ducts are the same size as called for on the working drawings.

3. Check joints for adequate grade of water-proof tape. Be sure that there are adequate ties to hold ducts from floating during placement of PCC. Stagger joints to maintain proper profile.

4. Check final profile of rigid duct. Consider camber in forms when eye-balling the drape. The first 15 feet from the end anchorage should also be given special attention to eliminate severe angular changes, Correction may be required due to superelevation. Use duct checking apparatus if required.

5l Check installation of intermediate grout vents if duct length is over 400 feet. Should be placed at the high point outside the limits of the bent cap.

6. Check that snap ties, tie bolts, etc., have not been placed through or just above or below ducts. Movement of ducts during stem pour can crush duct. Pass bullet through ducts to check for obstructions.

7. Make sure that all defects in ducts (breaks, crushed areas, etc.) have been repaired prior to concrete pour. Crushed ducts have caused problems in pulling strands and grouting,

8. Check reinforcing details. #4's at 12"oc at blockouts, 2-1/2" clearance for stirrups, 1'- 6" behind bearing plates, duct ties ..... also additional details shown on the working drawings.

9. Seal tendon openings to prevent water or debris from entering.

During stem pour:

1. If possible, cover ducts with an inch of concrete in bent cap area but allow for cap rebar clearance,

2. Avoid rock pockets by proper vibration of concrete, particularly around anchor plates and low areas of the duct's path.

3. Avoid impact dumping on ducts and dropping vibrator directly on the ducts.

4. Check alignment to see that no unusual movement takes place during pour.

After stem pour:

1. Ducts shall be checked to see if they are free of obstructions clear of water and debris. The ends of the ducts shall be recovered after the ducts are checked.

2. Repair damaged ducts.

3. Check if ducts are in line with trumpets.

During deck pour:

1. See that vent pipes are not damaged during pour.

2. Sketch or mark location of vents.

3. Be sure sufficient PCC test cylinders are taken.

Fabrication and placement of tendons:

1. There should be an adequate area to pull the strands. The strands should be protected from contamination during fabrication. Pushing the strand is common practice which provides better protection for the strand.

2. Contractor shall demonstrate that the ducts are free of water and debris. If water is encountered in the ducts, have the water removed.

3. Inspect the strands for rust.

4. Avoid unusual angle points when pulling the tendons into the ducts. Make use of rollers or pulleys.

5. Make sure tendons are installed in their proper locations.

6. Consider "rust free" period and possible need for corrosion inhibitor.

Prior to stressing:

1. See that Contractor has furnished required calibration curves for specific jack/gage combinations.

2. Check out pressure cell. The battery should be charged for 8 hrs maximum prior to usage. While using pressure cell in the field, only turn on while monitoring the contractor's jack.

3. Get familiar with all the prestressing procedures, potential problems with the particular system being used, Shop Plans, and elongation calculations.

4. Set up prestressing tables to document a complete record of each tendon stressed. Have elongation calculated beforehand, using actual "E" and "A"

5. Check to see if the stressing is from one end, both ends, or simultaneously from both ends.

6. Make sure you have discussed the stressing sequence with the Contractor.

During stressing:

1. Paint strands on both ends and check for slippage.

2. Plot at least one calibration curve per structure.

3. If elongation exceeds the acceptable limits, find out why.

4. If any anchorage hardware fails (even if the problem was corrected), call the area Senior or Headquarters Construction Office.

5. It is the policy of the Office of Structures Construction to monitor the contractor's jacks at the start of each day, but not necessarily while stressing every tendon. The Structure Representative may require additional monitoring which shall override OSC policy.

Grouting:

1. Check for missing strands before placing grout caps.
2. Make sure the grouting equipment meets specification and has adequate capacity for the job.
3. Make sure the cement is the correct type and protected from adverse conditions. The cement shall be supplied by an approved source and a Certificate of Compliance is required prior to placing the grout.
4. Use water/cement ratio not to exceed 5 gallons of water to one sack of cement.
5. Check with the Transportation Lab to be sure that proposed admixtures are acceptable.
6. Check efflux time in accordance with test method.
7. Make sure there is continuous agitation of grout during grouting.
8. Close outlet valve before closing inlet valve.
9. Have standby flushing equipment as required.

Miscellaneous

Most of the preceding inspection suggestions are also applicable to the Dywidag bar system and the VSL flat duct (thin slab) system. However, there are a number of additional items which should be considered when inspecting these two systems. Inspection suggestions for these items are on file with the Office of Structure Construction.

APPENDIX D - LOSSES AND ELONGATIONS

CALCULATIONS

The following appendix contains all the necessary information and formulas for calculating prestress losses and elongations for prestressed, post-tensioned structures. Included are example calculations for a simple-span structure stressed from one end and for a continuous structure stressed from one end. Also included is an anchor set example calculation.

It should be understood that the formulas and calculations are <u>approximate</u> and the engineer should apply reasonable tolerances when comparing the actual field measured elongations with those that are theoretical.

LOSSES

Post-tensioning of prestress box girder bridges must consider stress losses that will occur. The following are seven causes of prestress loss:

(1) Friction of the prestress steel with the duct and loss due to misalignment of the duct.

(2) Anchorage slip as the strand wedges seat at the bearing plate.

(3) Elastic shortening of the Concrete.

(4) Creep of the concrete.

(5) Shrinkage of the concrete.

(6) Relaxation of the prestress steel.

(7) The stressing Sequence.

Items 3 to 7 above are losses that take effect after stressing is complete and in accordance to Section 50-1-O8 of the Standard Specifications are assumed to be a total of 20 KSI for low relaxation wire and 32 KSI for normal relaxation wire and 22 KSI for bars.

Items 1 and 2 above are losses that occur during the stressing operation and can be calculated knowing the strand properties and the prestress tendon path configuration. These are the losses that are of most concern to the Structure Representative.

FRICTION LOSS

The losses due to friction can be calculated using the following formula:

$$T_0 = T_x e^{(ua)} \qquad \text{Equation 1}$$

where T_o = steel stress at the jacking end.

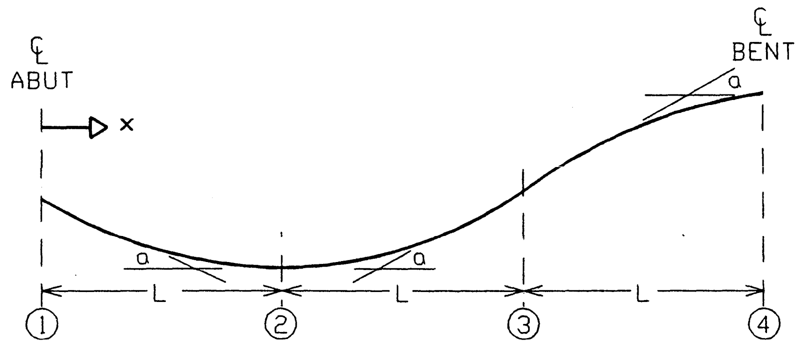
T_x = steel stress at any point x

e = base of Naperian logarithms

u = friction curvature coefficient

a = total angular change of the prestressing steel profile (tendon path) in radians from the jacking end to a point x.

L = length of prestressing steel from the jacking end to a point x.

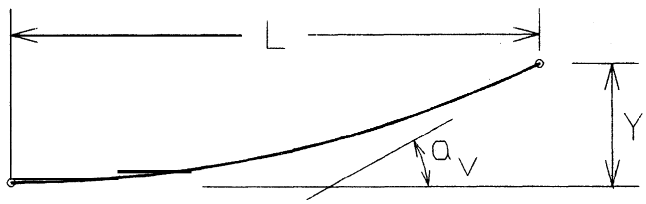


Section 50-l.09 of the Standard Specifications requires that the prestress ducts shall be rigid and galvanized. A friction coefficient of u = 0.20 is given in the Standard Specifications and the Contract Plans.

The prestress steel stress at any point x can be determined by manipulating Eqn 1 as follows:

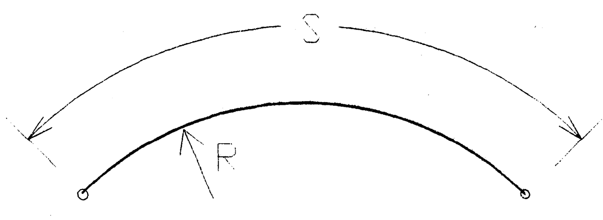
$$T_x = T_0 e^{-(ua)} \qquad \text{Equation 2}$$

To determine the correction 'a' due to the vertical curvature of the tendon path and for any horizontal bridge curvature that does exist, the following formulas can be used.



$$a_v = 2\frac{Y}{L}$$ Equation 3

$$a_H = \frac{s}{R}$$ Equation 4



$$a = \sqrt{(a_v)^2 + (a_H)^2}$$ Equation 5

Y = tendon drape in length L

S = length of curve from beginning of curve to point x

R = radius

To determine the loss due to friction expressed as a fraction of the temporary jacking stress is

$$\frac{T_o - T_x}{T_o} = 1-e^{-(ua)}$$ Equation 6

The loss that occurs due to the anchor set can be determined using the following approximate formulas:

$$\Delta f = \frac{2dx}{L}$$ Equation 7

$$x = \sqrt{\frac{E(\Delta L)L}{d}}$$ Equation 8

where Δf = change in stress due to anchor set

d = friction loss in length L

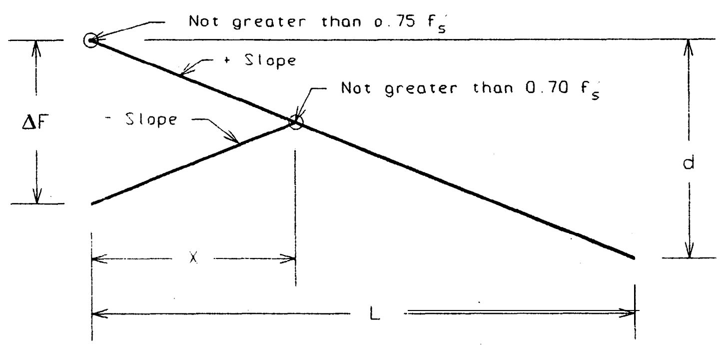
x = length influenced by the anchor set

L = distance to a point where the loss is known

ΔL = anchor set (normally = 3/8")

E = modulus of elasticity, assume 27 x 10 ksi

f_{jack} jacking stress



Section 50-1.08 of the Standard Specifications requires that the maximum temporary stress (jacking stress before anchor set) shall not exceed 75% of the specified minimum ultimate tensile strength of the prestressing steel. In addition, the initial stress shall not exceed 70% of the specified tensile strength of the prestressing steel. This initial stress is just after anchor set but before any long term losses occur, such as concrete shrinkage, relaxation of prestress steel, etc..

ELONGATIONS

As Structure Representative, it will be your responsibility to monitor the contractor's stressing operations. In addition to the use of a load indicator to check prestress force as described earlier in this manual the strand elongations must be measured and compared with the calculated theoretical elongations.

The contractor will submit elongation calculations on the working drawings using assumed values for the modulus of elasticity (E) and the area of the strand (A). When the prestress strand is delivered to the jobsite, it should have a white release tag with the actual E and A written on the back. If these values are not written on the back of this tag, then check the Category 41 file. The E and A should be on the TL-29. The theoretical elongations should be recalculated using the actual E and A.

The elongation between two points where the stress varies linearly can be given by the following equation:

$$\Delta = \frac{T_{avg}\ L}{E} \qquad \text{Equation 9}$$

where T_{avg} = average stress between two points $=(T_1 + T_2)/2$

E = Modulus of Elasticity

L = Length between T_1 and T_2

For almost all field situations the elongations based on the numerical average of the end stresses will yield sufficiently accurate results.

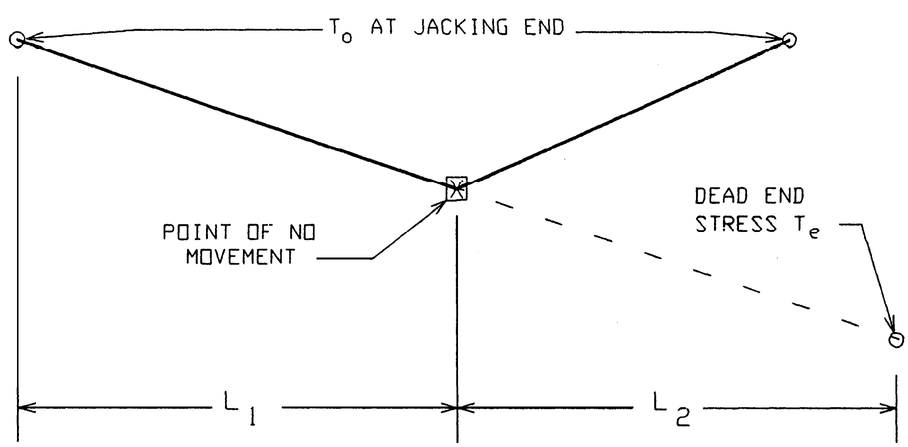
Equation 9 above applies to one-end stressing. For two end simultaneous stressing, the following derivation from Equation 9 can be used.

$$\Delta = \frac{T_0(1+\boxtimes)(L_1 + L_2)}{2E} \qquad \text{Equation 10}$$

where $\boxtimes$ = is the theoretical point of no movement.

The above formulas can be expanded for the entire structure once the theoretical point of no movement or minimum stress is known or calculated. In a continuous structure stressed with two end stressing, the point of no movement in a cable occurs where the losses right of the point equal the losses left of the same point. The force coefficient at that point is shown on the Contract Plans with the symbol, $\boxtimes$.

Reasonably accurate elongation calculations can be made for a structure given the following stress diagram:



If the structure is stressed non-simultaneously, the elongations at the jacking end can be estimated using the assumption that the dead end stress T_e is given by the following formula:

$$T_e = T_0(2\boxtimes - 1) \qquad \text{Equation 11}$$

The first and second elongations are

$$\Delta = \frac{T_0}{2E}\left[(1 + \boxtimes)\,L_1 + (3\boxtimes - 1)\,L_2\right] \qquad \text{Equation 12}$$

and

$$\Delta = \frac{T_0(1 - \boxtimes)\,L_2}{E} \qquad \text{Equation 13}$$

After obtaining the theoretical elongations, the measurable elongations are calculated. This is usually equal to 80% of the calculated elongation (using the actual E and A) from the first end and 100% from stressing the second end.

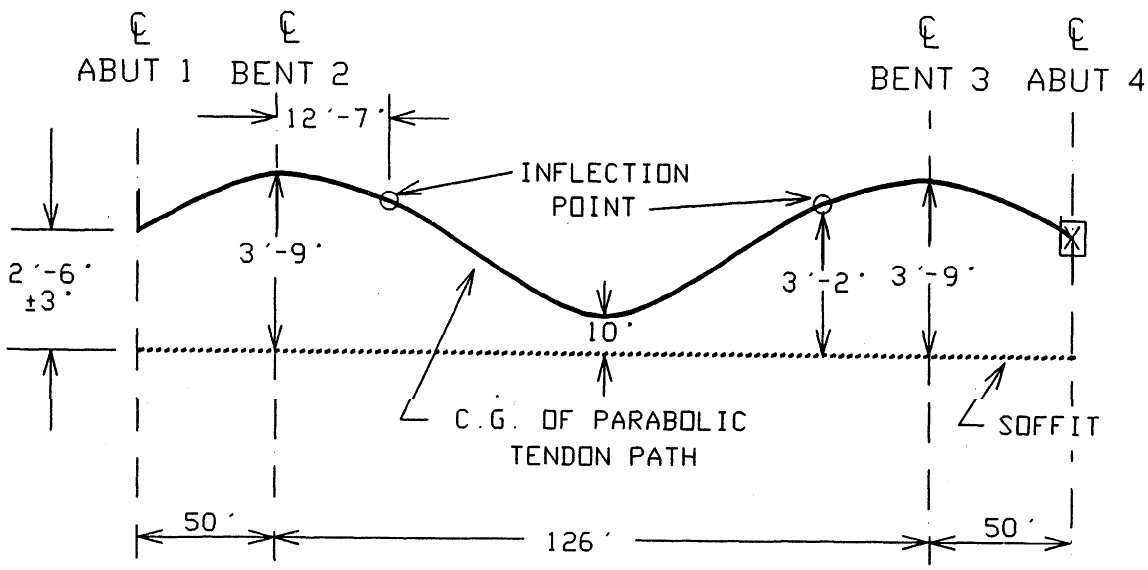
In most cases, the use of the $\boxtimes$ term as shown on the plans will yield acceptable results. Error is introduced because the calculations are based on a straight line stress variation and the term is usually an average of tendons and does not account for tendon path length variations.

EXAMPLE CALCULATIONS

Example l-Continuous Structure Stressed from one end

Given by the Contract Plans:

270 ksi low relaxation strand
P_{jack} = 5150 kips
A = 25.43 in^2
Anchor set = 3/8"
= 0.854 x jacking stress



CG path of the prestressing steel- Figure 1

Given by the Standard Specifications:

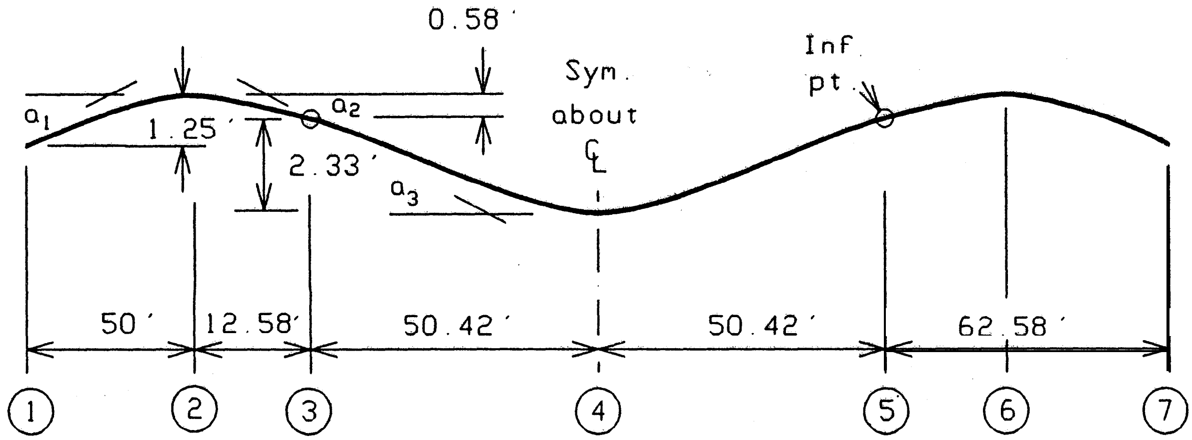
$$T_x = T_0 e^{-(ua)}$$

u = 0.20 for wire strand in rigid galvanized duct.

Losses after stressing for low relaxation steel = 20 ksi.

Find the total elongation?

(1) Total elongation



LOC	a	ua	Σua	$e^{-(ua)}$	x 202.5
1-2	0.050	0.0100	0.0100	0.990	200.5
2-3	0.092	0.0184	0.0284	0.972	196.8
3-4	0.093	0.0186	0.0470	0.954	193.2
4-5	0.093	0.0186	0.0656	0.937	189.7
5-6	0.092	0.0184	0.0840	0.919	186.1
6-7	0.050	0.0100	0.0940	0.910	184.3

Elongation (Δ) = PL/AE; P/A = T_{avg}

$$= \frac{T_{avg}\,L}{E}$$

Assume E = 27 x 10^3 ksi

Δ = [{(202.5 Ksi + 200.5 Ksi)/2}{50 ft} +
((200.5 + 196.8)/2){12.58} +
{(196.8 + 193.2)/2}{50.42} +
{(193.2 + 189.7)/2}{50.42} +
{(189.7 + 186.1)/2}{12.58} +
{(186.X + 184.3)/2}{50.00}](12 in/ft) / 27 x 10^3 Ksi

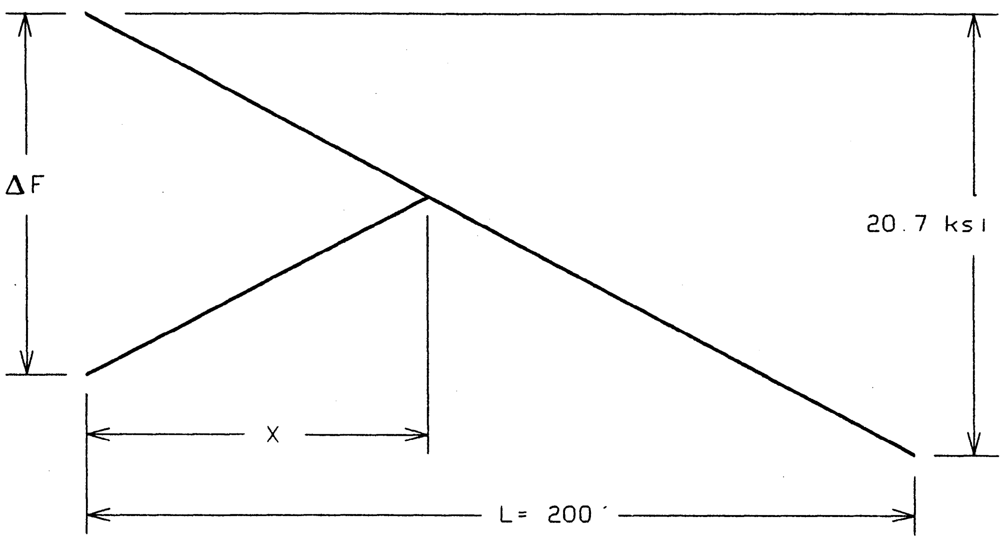
Δ = 19.4 in.

<u>Example 2 - Anchor set calculation</u>

The contract plans require a 3/8" anchor set. What is the change in stress at the anchorage end (jacking end) and how far into the structure does the anchor set loss extend?

Given: $E = 27 \times 10^3$ Ksi and $\Delta L = 3/8"$

Friction loss in length L = 20.7 Ksi



$$X = \sqrt{\frac{E(\Delta L)L}{d}} = \sqrt{\frac{(27 \times 10^3 \text{ Ksi})(0.375 \text{ in})(200 \text{ ft})}{(20.7 \text{ Ksi})(12 \text{ in/ft})}}$$

$$= 90.29 \text{ ft}$$

$$\Delta f = \frac{2dx}{L} = \frac{(2)(20.7 \text{ Ksi})(90.29 \text{ ft})}{200 \text{ ft}}$$

$$= 18.69 \text{ Ksi}$$

Example 3 - Simple span stressed at one end

Given by the Contract Plans:

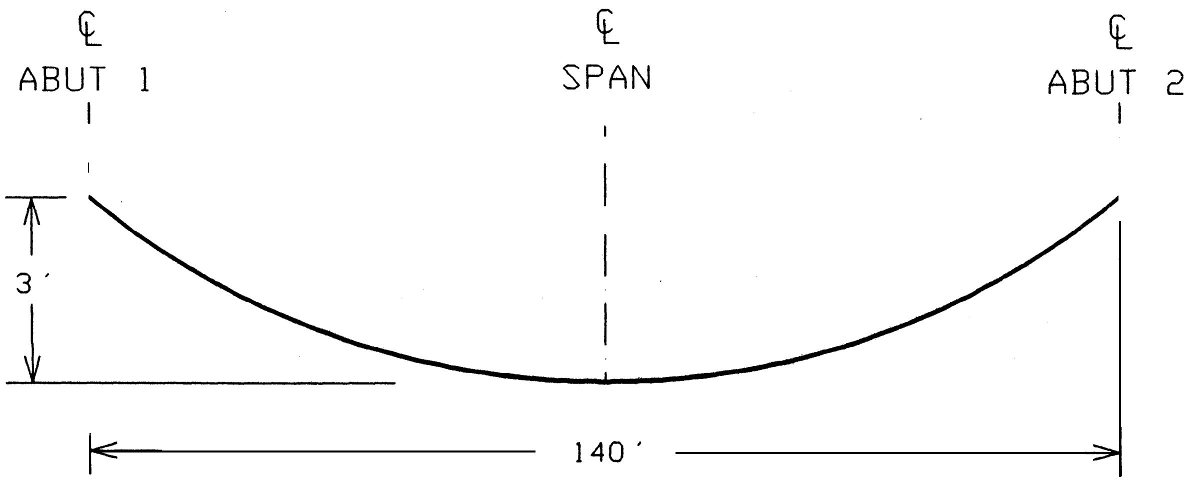
270 Ksi Low Relaxation Strand

P_{jack} = 12575 Kips

Area (A) of prestressing steel = 64.88 in^2

Anchor set = 3/8"

One end stressing



CG of the prestressing path

Find:

1. Is the jacking stress less than or equal to 0.75 f'_s ?
2. Is the intial stress after the anchor set less than or equal to 0.70 f'_s ?
3. Find the final working force at the centerline of span.
4. Find the theoretical elongation.

Example 3 (cont.)

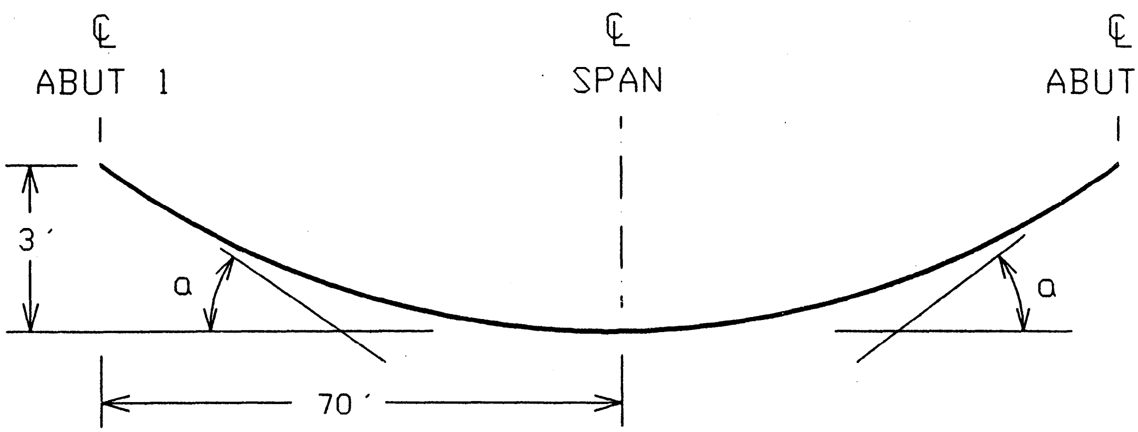
1. Jacking stress

$$\frac{P_{jack}}{\text{Area}(A)} = \frac{12575 \text{ Kips}}{64.88 \text{ in}^2}$$

$$= 193.8 \text{ Ksi}$$

$0.75(270 \text{ Ksi}) = 202.5 \text{ Ksi OK}$

2. Intial stress at the dead end (abutment 2)



$$a = \frac{(2)(3)}{70} = 0.0857 \times 2 = 0.1714$$

$$T_x = T_o e^{-(ua)} = (193.8)e^{-[(0.20)(0.1714)]}$$

$$T_x = (193.8)(0.9663) = 187.3 \text{ Ksi}$$

Example 3 (cont.)

Effect of the anchor set.

$$X = \sqrt{\frac{E(\Delta L)L}{d}} = \sqrt{\frac{(27 \times 10^3 \text{ Ksi})(0.375 \text{ in})(140 \text{ ft})}{(193.8 - 187.3 \text{ Ksi})(12 \text{ in/ft})}}$$

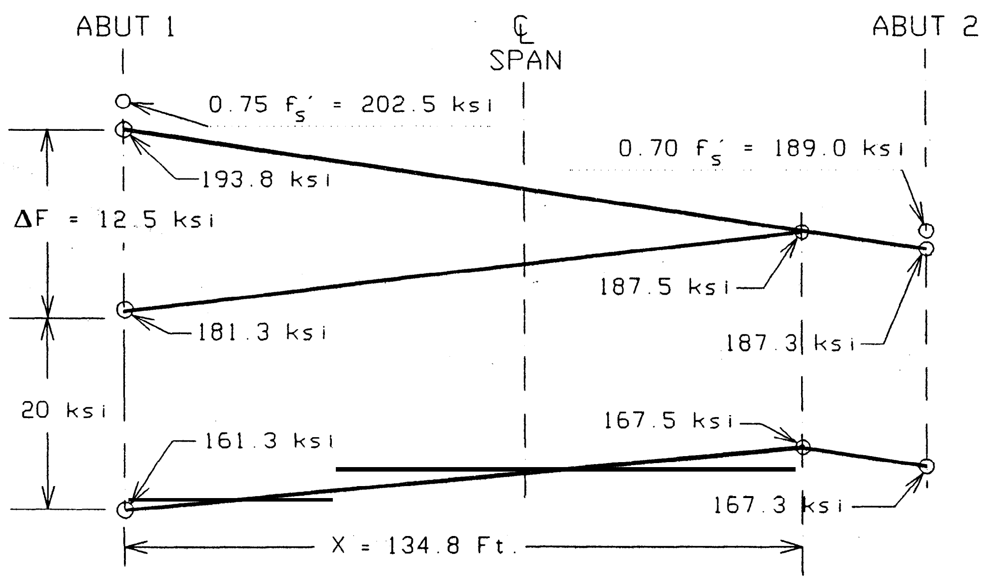
$$= 134.5 \text{ ft}$$

$$\Delta F = \frac{2dx}{L} = \frac{(2)(193.8 - 187.3 \text{ Ksi})(134.5 \text{ ft})}{140 \text{ ft}}$$

$$= 12.5 \text{ Ksi}$$

Intial stress after anchor set.

Stress Diagram



Initial stress = 187.5 Ksi < 0.70 f'_s = 189.0 Ksi

3. Final working force at the centerline of span.

(164.3 Ksi)(64.88 in^2) = 10,660 Kips

4. Theoritical elongation

$$= \frac{T_{avg} L}{E} = \frac{[(193.8 + 187.3)/2 \text{ Ksi}](140 \text{ ft})(12 \text{ in/ft})}{27 \times 10^3 \text{ Ksi}}$$

$$= 11.9 \text{ inches}$$

APPENDIX E - CALIFORNIA TEST #541

STATE OF CALIFOFNIA-BUSINESS, TRANSPORTATiON AND HOUSING AGENCY PETE WILSON, Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY
P.O. BOX 19128
SACRAMENTO, CA 95819

(916) 444-4800

California Test 541
1978

METHOD OF TEST FOR FLOW OF GROUT MIXTURES (FLOW CONE METHOD)

A. SCOPE

The procedure to be used for determining the flow of grout mixtures is described in this test method.

B. APPARATUS

1. Flow cone and supporting ring conforming to the dimensions indicated in Figure 1.
2. Stop watch having a least reading of not more than 0.1 second.
3. Rubber stoppers, Size 00.
4. Sample container of 4 liter min. capacity (a 6" x 12" concrete mold is adequate.)
5. Suitable stand for supporting ring. (5-gallon paint bucket may be used, see Figure 2.)

C. SAMPLE

The test sample shall be approximately 4000 ml of grout.

D. DETERMINATION OF EFFLUX TIME

1. Dampen flow cone and allow any excess water to drain. Place the cone in the supporting ring and insert the rubber stopper.
2. Level the cone, then pour the grout from the sample container into the cone until the grout surface is level with the bottom of the three holes in the side of the cone.
3. Remove the stopper and start the stopwatch simultaneously.
4. Stop the stopwatch at the first break or change in the continuous flow of grout from the discharge tube. Record the indicated time of efflux to the nearest 0.1 second.
5. Dispose of the grout sample, rinse the equipment.

E. DETERMINATION OF EFFLUX AFTER QUIESCENCE

1. Fill cone with grout as previously described, using remainder of 4000 ml sample.
2. Allow grout to rest in cone for 20 minutes ± 15 seconds from the instant the cone is filled to the time the efflux time is to be measured. After the 20 minute quiescent period, determine efflux time as described previously in Section "D".
3. Record efflux time of the grout.

F. PRECAUTIONS

The cone must be placed in a location that is free from vibration.

The cone must be kept clean for cement buildup especially in or near the orifice and nozzle.

End of Test (2 pgs) on Calif. 541

California Test 541
1978

FIGURE 1

GROUT FLOW CONE

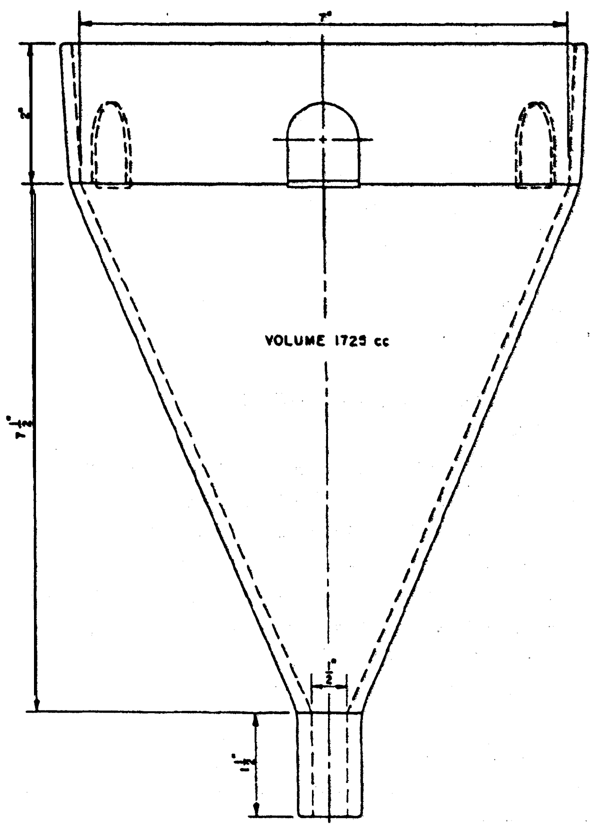


FIGURE 2

GROUT EQUIPMENT

REFERENCES

" STANDARD SPECIFICATIONS "

Section 50 - Prestressing Concrete
Section 51 - Concrete Structures

" STANDARD PLANS "

Standard Plan B8-5

" BRIDGE CONSTRUCTION RECORDS AND PROCEDURES "

Memo 160-l.O......	Camber for simple span Cast-in-Place Prestressed Box Girder Bridges
Memo 160-2.0	Lab Notification of Stressing Data
Memo 160-3-O	Prestressing Cast-in Place Concrete
Memo 160-4.0	Grouting Post-Tensioning Girder Tendons
Memo 160-5.0......	Testing Flow of Neat Cement Grout
Memo 160-6.0......	Prestressed Concrete Working Drawings and Microfilms
Memo 160-7.0	Stressing Incomplete Bridges
Memo 160-8.0	Patching Concrete under Prestress Bearing Plates
Memo 145-7.0......	Adjustable template for checking profiles of ducts in Post-Tensioned, Prestressed, concrete girders.

" PRESTRESS COMMITTEE "

" OFFICE OF STRUCTURES CONSTRUCTION, SACRAMENTO "

" DIVISION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH " (TRANSLAB)